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AN ECONOMIC INVESTIGATION OF SOLID JOURNAL BEARING OPERATION IN FREIGHT SERVICE ON TWO LARGE CLASS I RAILWAYS

ROY M. WRIGHT
Late Research Assistant Professor in Mechanical Engineering

DONALD E. TAYLOR
Special Research Assistant in Mechanical Engineering

ROBERT FERBER
Research Associate Professor of Economics in Bureau of Economic and Business Research

FRANCES S. DOTSON
Research Assistant in Bureau of Economic and Business Research and Mechanical Engineering

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ABSTRACT

Investigations were conducted on two large railroads to determine both the direct and indirect costs traceable to the use of solid journal bearings on freight cars for the years 1948 and 1951. Corollary studies were made of the factors influencing hot box occurrence.

The two roads which cooperated in the investigations were Railroad A, a north-south route running from the Great Lakes to the Gulf Coast, and Railroad B, a transcontinental route running from the head of the Great Lakes to the Northwest Pacific Coast.

The car miles per hot box set-off between division terminals on the two railroads were as follows:

	1948	*1951*
Railroad A	120,570	84,195
Railroad B	223,263	145,944

Though these values seem to indicate that Railroad B had a lower hot box occurrence than Railroad A, differences which were found to exist in the handling of cars developing hot boxes made the number of car miles per hot box set off a poor measure of relative hot box troubles between terminals on the two railroads. It was also found that car miles per hot box set off was a poor measure of over-all bearing performance since in the cases studied, the number of cars repaired for hot boxes was between 2.5 and 4.4 times as great as the number of set-offs. Considering all types of hot boxes, the resulting estimated values for the car miles per hot box given final repairs (temporary repairs not included) were as follows:

	1948	*1951*
Railroad A	43,820	33,229
Railroad B	44,681	29,408

Thus, within a given year, when all hot boxes were considered, both railroads obtained about the same bearing performance.

Though hot boxes, accidents, and fires attributable to solid journal bearings are matters of great interest and concern, only 20-34 percent of the determined costs resulted from these bearing service failures. The costs of routine inspection and lubrication were found to be very important; they accounted for 56-68 percent of the determined costs.

The total determined costs of solid journal bearing operation per 1000 car miles were estimated to be as follows:

ABSTRACT (Concluded)

	1948	*1951*
Railroad A	$5.33	$7.59
Railroad B	$5.43	$8.53

Important costs arising from solid journal bearing operation which could not be determined are thoroughly discussed in Chapter V.

Both service failures and the everyday lubrication requirements of solid journal bearings contribute largely to uneconomical characteristics of present car repair and inspection practices, among which are slow movement of trains through intermediate terminals and the necessity of having numerous, small car repair points. Costs due to these features, in part attributable to solid bearing operation, have not been evaluated.

Studies of factors influencing the development of hot boxes indicated that extreme temperatures, increase of car weight, and increase of train speed all increased the development of hot boxes. It was also discovered that cars develop hot boxes after moving relatively short distances from terminals and loading points.

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I. INTRODUCTION

1. Object and Scope of Investigation

In recent years the railway industry has focused its attention on the performance and costs of operation of solid journal bearings in freight service. A need existed for a complete over-all study to obtain information regarding the situation.

A preliminary survey of four representative railroads was conducted during July, 1948, to determine whether the railroads were interested in cooperating with the University of Illinois in making a study of the engineering and economic aspects of freight car bearings. The survey revealed keen interest on the part of the railroads, and a willingness to cooperate with the University in the study. With this assurance of support the University activated an investigation of solid journal bearing operation on February 1, 1949.

The main object of the investigation was to determine the economic effects of the use of solid journal bearings on railroad freight cars. The investigation was to include both the direct and indirect costs traceable to the use of solid journal bearings, and the effects of these costs on railroad operation. Initially, the year 1948 was selected for study because at the time the investigation was activated it was the most recent complete year. As time passed it became apparent that important increases in costs of operation took place after 1948, due to both operational and economic influences. To illustrate the causes and the magnitude of these increases, cost estimates were also made for the year 1951.

The investigation was conducted by making a complete survey of solid journal bearing operations on two large representative railroads. The two railroads cooperated fully with the University to the extent of allowing the use of all available information pertaining to solid journal bearing operations on their lines. Because of interest on the part of these cooperating railroads, the investigation also included corollary studies of factors influencing hot box occurrence.

Acknowledgment is made to the Bureau of Economic and Business Research for carrying on the statistical and portions of the economic phases of the investigation, and to H. J. Schrader, Research Professor of Theoretical and Applied Mechanics and M. K. Fahnestock, Research Professor of Mechanical Engineering for their advisory assistance.

2. Standard Solid Journal Bearing

The costs presented in this report apply to the costs of operating freight cars equipped with the standard solid journal bearing assembly. This assembly includes an axle journal, babbitt-lined bronze bearing, wedge, journal box lid, dust guard, dust guard plug, and journal box packing. (See Fig. 1.) The journal box packing is an oil-saturated mass of cotton and/or wool threads which closely surrounds the bottom of the axle journal. When the journal rotates, the packing coats it with an oil film which provides lubrication between the journal and the bearing.

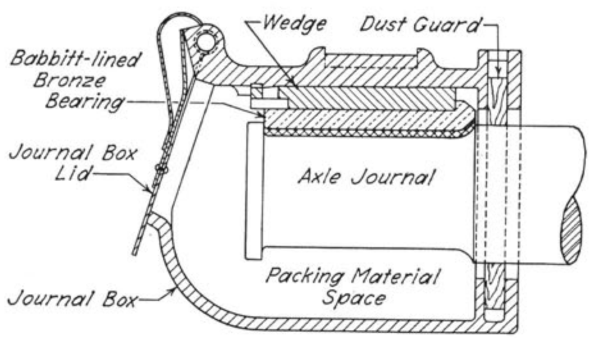

Fig. 1. Standard Solid Journal Bearing

3. Designation of Bearing Service Failures

Solid journal bearing service failures include hot boxes, accidents resulting from broken or burned-off journals, and fires caused by hot boxes. It should be noted that broken and burned-off journals are regarded as accidents and not as a type of hot box.

In this report, hot boxes have been grouped into four general types, classified according to the repairs made to the car:

(1) R and R — This abbreviation refers to hot boxes repaired by removal, inspection and replacement of the journal bearing or wedge. No parts other than the packing are renewed in these repairs. Where final repairs were made in this manner, the bearing assemblies had been discovered in the first stages of overheating, before the babbitt lining of the bearing or the journal surface had been damaged.

(2) Rebrass — Hot boxes repaired by renewing the journal bearing and repacking the journal box with clean packing. Where final repairs were made in this manner, the bearing temperature had usually been high enough to cause the babbitt lining of the bearing to become plastic and flow, but the overheating was not sufficiently advanced to damage the journal surface.

(3) Other Work — This refers to cars repaired by train crews where repairs consisted of anything from the addition of oil to an R and R. The degree of overheating in these cases is unknown, but most of the cars so repaired were given further repairs before they were forwarded to a destination.

(4) Cut Journal — A cut journal results from a serious overheating. Usually the babbitt lining of the bearing has melted out, permitting the bronze backing of the bearing to cut or score the axle journal. Repairs are effected by renewing the axle having the cut journal. Since wheels and axle are mounted as a unit, this requires changing a pair of wheels. Ordinarily new bearings are applied to all journals on the axles installed. It is permissible, however, to apply second-hand bearings, since a cut journal is a handling line defect. The axle having the cut journal may be reconditioned and later returned to service if it is not condemnable by any provisions of Sec. XIV of the "Wheel and Axle Manual" of the AAR. The cut journal, if not detected in time, may eventually result in a burned-off journal.

A complete rupture of an axle journal usually results in a derailment. When axle journals fail as the result of overheating they are usually termed burned-off journals. Some axle journals fail while operating at normal running temperatures; these are termed broken journals. Examination of broken journals ordinarily reveals evidence of previous overheating and indications that the journal was cut and then reconditioned.

4. Rules and Procedures Involving Solid Journal Bearings

The "Association of American Railroads Code of Rules Governing the Condition of, and Repairs to, Freight and Passenger Cars for the Interchange of Traffic" (referred to hereafter as the AAR Code) contains several rules which directly pertain to solid journal bearing operations. The most important of these, and the procedures established by their provisions, are as follows:

Rule 1 — This rule states that "each railroad is responsible for the condition of all cars on its line, and must give to all equal care as to inspection and lubrication." In effect, this places the responsibility for a bearing lubrication failure directly on the handling road. Inspection and lubrication of solid journal bearings require considerable labor and cause the loss of a large number of car days. Ordinarily, at large classification yards, the standard procedure is to oil the bearings on all cars leaving the yard.

Rule 3 — This rule specifies that, to be acceptable in interchange, cars equipped with solid journal bearings must use materials and designs in the bearing assemblies which comply with AAR specifications as minimum requirements.

Rule 66 — The general provisions of this rule state that all journal boxes on each freight car in interchange must be periodically cleaned and repacked with acceptable packing as determined by the repack date which is stenciled on the car. The basic time period between repackings is fifteen months. It is subject to modifications, explained fully in Rule 66, which allow for various repair situations. At the time of periodic repacking, each journal box must be jacked and the bearing and wedge removed for inspection. The rule states clearly when the bearing or wedge shall be considered as requiring renewal. This maintenance is assumed to be the result of normal wear and fair usage, and the car owner is billed for the repacking of the car and any replacement of parts. It is further specified that the work should be done only when cars are on repair tracks, or on freight house, icing, cleaning, or storage tracks, provided that proper facilities are available for doing the work at these locations.

Rule 84 — This rule places the responsibility for the costs of repairs to a cut journal upon the line which was handling the car at the time the journal became cut.

Rule 86 — The wear limits for car axles are contained in this rule.

II. PLAN OF INVESTIGATION

Initially, a survey plan was prepared for the complete study of a railroad, listing the information desired and the possible sources of this information. Railroad A was then selected as the first railroad to be included in the study as one of a group of representative railroads. While the study was in progress on Railroad A, the survey plan was greatly modified and improved. When this improved plan was applied to Railroad B, it became evident that some flexibility must be incorporated because of the differences in operation and organization of railroads.

The plan of investigation may be outlined by listing various locations on the railroad and the information ordinarily available at each location. The outline is arranged in a chronological order convenient for conducting the investigation. Comments have been inserted in the outline for explanatory purposes.

OUTLINE OF INVESTIGATION PLAN

Location	Information Obtained
A. General Offices	*(System totals unless otherwise stated)*
1. Operating Vice-President	a. Operating Statistics, Monthly by Divisions b. Annual Reports Form A
2. Transportation Department	a. Cars handled through terminals
3. Accounting Department	a. Loaded and empty car miles by division b. Cost of detouring trains c. Cost of fire damage from hot boxes d. Fuel consumption, mileage, and gross ton miles hauled for locomotives by classes e. Monthly ICC Performance Reports Forms OS-A, OS-C, OS-E, and OS-F f. Time slips for men making on-line repairs (when available here)
4. Freight Claim Department	a. Cost of damage to lading in accidents
5. Traffic Department	a. Freight commodity statistics

6. Stores Department	a. Amounts of bearing materials issued b. Number or tons of axles scrapped
7. Mechanical Department (Note: Mechanical Department reports are usually monthly reports, and are given either by master mechanic's jurisdiction or by individual repair point.)	a. Hot boxes set off between division terminals, by month and by division b. Total wheels changed for all defects, and total wheels changed for cut journals c. Cars repacked under Rule 66, AAR Code d. Labor force reports e. Costs of journal bearing accidents f. Delays to trains due to journal bearing accidents g. List of repair tracks

(Note: The information obtained from the general offices served as a guide for proceeding with the survey at on-line points, since the dense traffic locations and the important repair locations were then known.)

B. Division Offices	(*Division totals unless otherwise stated*)
1. Superintendent	a. Cars handled through terminals b. Report of hot boxes set off between division terminals, by month and by individual car
2. Chief Train Dispatcher	a. Delays to trains due to mechanical failures b. Lading of cars set off with hot boxes c. Information on tonnage reductions during low temperature operation d. Valuable information on general practices in railroad operation
3. Master Mechanic (Note: In some cases items a, b, and c may be obtained at the General Offices of the Mechanical Department.)	a. Total wheels changed for all defects, and total wheels changed for cut journals at each division repair track b. Number of cars repacked under AAR Code Rule 66 at each division repair track c. Labor force report for each point on the division d. Inspector's reports of repairs to hot boxes set off between division terminals e. Information of a general nature pertaining to the investigation

(Note: Items a and b were very important in deciding at which points samples of repairs to cars should be taken.)

C. Local Repair Tracks	
1. Car Foreman	a. Samples of billing and repair cards for cars repaired for hot boxes
	b. Samples of billing and repair cards for cars shown repacked according to provisions of Rule 66, AAR Code
	c. Valuable information on practices of freight car repairs
2. Local Storekeeper	a. Bearing materials issued locally
	b. Time slips for men making on-line repairs (when available here)
D. Classification Yards	a. Time required for inspection and servicing of journal bearings
1. Lead Car Inspector	b. Information concerning journal bearing inspection and servicing procedures.

In making a survey, the information listed under Item A would be obtained first. The information listed under Items B, C, and D would be obtained as the various points on the railroad were visited during the course of the study. All information desired at any one point could be obtained during one visit. However, return trips to a point are sometimes desirable after more complete understanding of conditions on the particular railroad is achieved.

As previously mentioned, the outline cannot be regarded as a rigid one which may be followed on all railroads in every detail. Some railroads may keep records in a different manner, and the source shown for a given item of information may change. Also, the operating procedures on various railroads may differ, which might make additional information desirable or make some of the listed information superfluous. By conducting any future survey in the order indicated, the effects of these differences in organization and operation on delaying the study should be kept at a minimum.

III. THE TWO RAILROADS STUDIED

5. Description

The size of each railroad has been indicated in Table 1 by means of comparison rather than by listing actual magnitudes. The type of traffic carried by the railroads studied is shown in Table 2. The traffic density on each railroad studied is slightly above the average for all railroads of their respective regions.

Railroad A is primarily a north-south route running from the Great Lakes to the Gulf Coast. The territory served by Railroad A furnishes a very diversified traffic. Therefore operations on Railroad A are very close to the average for all railroads with respect to commodities handled. Another result of the diversified traffic is that seasonal peaks in freight traffic are minor and localized.

Table 1

Size of Railroads Studied, Year 1951

Standard Compared	Percent of Total for All Class I Line-Haul Railways		Rank Compared with Other Individual Railroads	
	Railroad A	*Railroad B*	*Railroad A*	*Railroad B*
Miles of Road Operated	2.91	3.70	13	7
Freight Train Miles	3.54	2.56	7	13
Freight Car Miles	3.30	2.56	8	12
Gross Ton Miles	3.26	2.68	8	12
Net Ton Miles (Rev. and Non-Rev.)	3.24	2.82	8	11
Freight Cars Owned	3.10	2.16	10	15

Before 1951, all road freight traffic was handled with coal burning steam locomotives. Late in 1951 diesel electric locomotives were put into limited use in road freight service.

The terrain through which the road operates presents no serious operating problems from the standpoint of curvature or grades. The tonnage handled per train and the average train speed compares favorably with those of other roads of the region.

The road is confronted with a wide variation in weather conditions. Winter operating conditions present a contrast between the rather severe climate of the Great Lakes region and the temperate one of the central Gulf Coast. Summer temperatures of the entire area served are high.

Railroad B is an important transcontinental route running from the head of the Great Lakes to the Northwest Pacific Coast. A large part of the traffic comes from agricultural and mining operations. The handling of agricultural products reaches a peak from August through October.

Many of the mining operations shut down from November through March. These situations cause large seasonal fluctuations in the amount of traffic handled. From August through October, traffic is approximately 1.5 times as heavy as from December through February.

Most road freight service is performed by oil-burning steam, diesel-electric, and electric locomotives. A small amount of freight is handled by coal-burning steam locomotives, but their use is being eliminated.

Table 2
Comparison of Traffic Carried on Railroads Studied With Traffic Carried on All Class I Line-Haul Railways, Year 1951

Commodity Group	Tons of Revenue Freight Carried, Percent		
	Railroad A	*Railroad B*	*All Class I Line-Haul Railways*
Products of Agriculture	11.70	15.03	9.09
Animals and Products	1.74	0.72	1.15
Products of Mines	50.81	62.95	51.20
Products of Forests	9.21	7.51	6.68
Manufactures and Misc.	25.52	13.34	30.72
Forwarder Traffic	0.23	0.01	0.42
L.C.L. Freight	0.79	0.44	0.74
Total	100.00	100.00	100.00

The road crosses both the Rocky Mountains and the Cascade Range. Other than in these mountainous areas, grades are moderate. The tonnage handled per train and the average train speed are approximately the same as the average for all roads in the region.

With the exception of the area west of the Cascades, the entire region through which the railroad runs experiences extremes of weather conditions, with warm summers and very severe winters.

6. Distances Between Freight Car Repair Tracks

Generally, the distances between repair tracks are much greater on B than on A.

	Railroad A	*Railroad B*
Locations where repair tracks are more than 200 miles apart	3	11
Miles of road operated per repair track	177	309
Miles of main track per repair track	209	336

The relatively great distance between repair tracks has an important influence on the way road mechanical failures are handled on Railroad B.

7. Bearing Inspection and Servicing Procedures

On both Railroads A and B journal bearing inspection was usually a part of the routine inspection given to trains arriving at and departing from classification yards and intermediate terminals. The attention given to the bearings by car inspectors or oilers assigned to train yard service varied at different points.

The bearing inspection procedures used at large classification points and originating yards were of the following general pattern:

(1) Inbound inspection — Upon arrival of the cars in the receiving yard, inspectors opened the journal boxes and observed the condition of the box interior hooking the journals to locate waste grabs* or cut journals. In addition, it was a general practice on Railroad A to touch the ends of the journals with the bare hand in order to locate bearings running at above normal temperatures. This procedure was also in limited use on Railroad B; however mechanical personnel stated that such a thermal inspection of the journals could not be satisfactorily performed during severe winter weather. During the inspection, cars found defective for any reason were carded to be sent to the repair track. Cars found in good condition were sent through the normal classification procedure with the journal box lids in the open position.

(2) Departure yard servicing — After the cars were classified and assembled as a train in the departure yard, they were given a final inspection and servicing. In this inspection the car inspectors were primarily concerned with the air brake equipment, while the car oilers attended to the condition of the journal boxes. The waste was firmly packed down and oil was added where necessary. Journal boxes having waste grabs which occurred in classification were jacked and new bearings applied if necessary. This procedure was repeated until the entire train had been so serviced. Usually, individual journal boxes were completely serviced by one man, but at some locations on Railroad B a different system was used during severe winter weather. Under this system, one man added hot oil to the journal boxes to soften up the waste. Then a second man packed down and adjusted the waste.

The distance between points where the boxes were completely serviced varied from 235-500 miles on Railroad A and from 100-385 on Railroad B.

The amount of inspection and oiling attention given to freight car journal bearings at other intermediate inspection terminals varied from point to point. Complete inspection and oiling, as outlined above, was usually given to all cars originating locally in loaded movement. Beyond this, the amount of attention given to other cars passing through the terminals depended on the number of men available to do the work. Ordinarily there were too few to service completely all the cars passing through the yard. There were more such locations on road A than on road B. This does not imply poorer inspection on Railroad A, since the increased frequency of these points is largely caused by the fact that inspection terminals are separated by smaller distances on Railroad A.

* Waste grab — strands of journal box packing wedged between the journal and the bearing.

At freight houses and other similar places on Railroad A where a large number of cars were loaded with freight for high-speed movement, the cars were given an inspection and servicing while being loaded which was more thorough than the attention given to cars in the classification yards. Oilers at these locations were personally responsible for the bearing performance of cars serviced. At the freight houses there was more time to complete the work than in the classification yards. Closer inspection was made to locate lint or waste along the oil groove of the bearing. Bearings suspected of having any defect whatsoever were removed and inspected. The bearing performance of cars so serviced seemed to indicate good results from such special attention. It must be pointed out, however, that these cars were usually loaded very lightly.

8. Repair Procedures on Service Failures of Journal Bearings

There were considerable differences between the procedures used on the two railroads in the repairing of service failures of journal bearings, as may be illustrated by a short description.

(*a*) *Railroad A* — Cars developing hot boxes between division terminals were set out of the train, and the train crews made no attempt to repair them. Before further movement, all cars set out in this manner were inspected and repaired by car inspectors sent out from repair tracks. These repairs were occasionally made on the same day that the car was set out, but more often on the following day.

Usually, the man making the repairs used a small truck to get to the station where the car was set out. In rare instances, the car was set out in a location impossible to reach from a highway or road; a railway section car was then used. The repairs ordinarily consisted of rebrassing the hot box. A flame depressant compound, also known as "no-hot" or "hot box cooling compound," containing a polishing agent, was used to prevent fires from breaking out when moving cars with cut journals to repair tracks for wheel change. Some inspectors also used this compound on cars which did not have cut journals; however, this practice necessitated repacking the journal box after the car had moved to the nearest repair track. If the compound was not used on cars which were only rebrassed, they could continue on to destination without again requiring attention, provided that no further defects arose. A rare exception to this road repair procedure occurred when the inspector considered the car unsafe for movement due to the journal being broken, cracked, or very badly cut. In this case the necessary men, tools, and material were sent out from the repair track, and the wheels were changed on the car at the station at which it was set out.

After receiving the first repairs and inspection the car was moved, usually in a local freight train, to the nearest point having a repair track. If the local train had already passed the station where the car was to be picked up, the car was usually left there until the following day; however, in this case, sometimes a through train picked up the car during the night. The local train usually arrived at the repair point in the afternoon, and the cars in the train were classified. A car needing further work was switched to a "bad order" track on which defective cars were placed. A car which did not require work was classified for movement in a through train, and usually left the point some time during the night. Usually at repair points some cars were "bad ordered" for bearing defects by inspectors in the train yard, and were also switched to the "bad order" track. Defective cars on the "bad order" track were placed on the repair track in the morning before repair forces began their working day.

A car with a cut journal required replacement of the axle having the cut journal. Because changing wheels in a car requires a great deal of time, it was common for a car with a cut journal to be held over on the repair track a second day when repair track forces were busy. Cars rebrassed and "R and R" usually were ready to move off of the track at the end of one day.

Cars on the repair track were customarily switched shortly after the close of the working day of the repair track force. The repaired cars were classified, and later in the evening were put into through trains for forwarding to destination.

(*b*) *Railroad B* — On manifest trains, cars developing hot boxes between division terminals were set out and the train crews made no attempt to repair them. On slow tonnage or local trains, cars with hot boxes were not immediately set out, but attempts were made by the train crews to make repairs which would at least permit handling to the next terminal. If such a car gave repeated trouble, and handling it to the next terminal would involve excessive delay to the train, the car was then set out. Cars set out of manifest, tonnage, or local trains were ordinarily picked up by the next tonnage or local train headed in the same direction, necessary repairs for movement being made by the crew of the train making the pickup. If cars picked up in this manner caused repeated delays, they might be set out again. Thus, a single defect developed between terminals may have resulted in a car being set out more than once while enroute to a repair terminal.

The repairs to hot boxes made by train crews varied from addition of oil to renewal of bearings. No wheel changes were made by train crews. Cabooses on Railroad B were supplied with bearings, packing, oil, flame depressant, and tools necessary for the work. In some cases where the journal was not cut, the repairs made by the train crews enabled the car to proceed to its destination without any further delay. In the majority of the instances, however, final repairs at the repair track were required.

When conductors had doubts as to the safety of movement of hot box set-offs, car repairmen (usually two or three, transported in a truck along with their supplies) were sent out from the nearest repair track. Ordinarily the necessary repairs were made on the day after the cars were set out. In rare instances highways were impassable because of weather conditions, or good roads were not available; the men were then sent out in a special railway car. On these road trips repairs consisted of either rewheeling or rebrassing the defective car. If the car had a cut journal, the distance to the nearest repair track and the condition of the journal influenced the type of road repairs. If the distance was long or the journal was badly cut, the wheels were usually changed, which constituted final repairs. Otherwise the car was sometimes rebrassed and sent to the repair track for final repairs. Cars without cut journals were rebrassed and forwarded to destination.

Procedures used in repair terminals on Railroad B for switching of defective cars to and from the repair track, actual repairs, and forwarding of repaired cars to their destination, were all very similar to those described for Railroad A.

9. Bearing Performance

In Fig. 2, the common measure of bearing performance, car miles per set-off, is used to compare the annual performance of Railroads A and B for 1943-1951. The annual performance of all railroads reporting statistics to the AAR is also shown for those years in which complete information was collected by the AAR. On this basis it appears that Railroad B has a much better performance record than Railroad A. It has already been pointed out that considerable differences were found to exist in the policies of Railroads A and B regarding the handling of cars developing hot boxes between terminals. On Railroad A such cars were immediately set out; on Railroad B considerable efforts were made to carry them forward into a repair terminal. This policy in itself would tend toward a much better set-off performance. At the same time, actual hot box delays and troubles between terminals on Railroad B may have equaled or exceeded in severity those experienced on Railroad A.

The comparisons presented in Fig. 3, for 1948 and 1951, further illustrate this point. Figure 3 is based upon the number of hot boxes of various types which were calculated from supporting data by methods explained in Appendix A. An explanation of the method of assigning hot boxes to the different categories of Fig. 3 is given in Appendix H.

Bars (1) show car miles per set-off. Bars (2) show the car miles per set-off delay plus road delays caused by the same cars preliminary to set-off. Bars (3) are based on the cases included in (2) plus road delays caused by cars which were not set off.

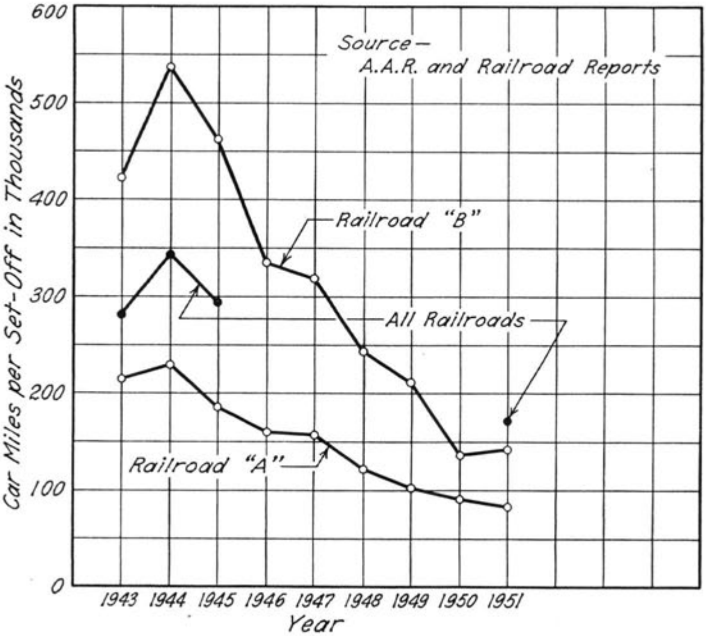

Fig. 2. Freight Car Miles Per Hot Box Set Off Between Terminals for All Railroads and Railroads A and B, 1943-51

In both 1948 and 1951, Railroad B had a much better set-off performance than Railroad A. This might seem to indicate less interference with road operations on Railroad B; however, when bars (3) are compared, it is evident that actually the reverse is true.

The actual number of cars causing the road delays where no set-offs were made is unknown, since one car may have caused two or more delays. Also, an indeterminate number of the cars involved in these delays required no further attention and were forwarded to destination. It is probable, however, that the majority of them required final repairs at repair tracks. At any rate, due to a lack of sufficient data regarding the cars, it was impossible to estimate the total number of individual hot boxes given final repairs on Railroad B.

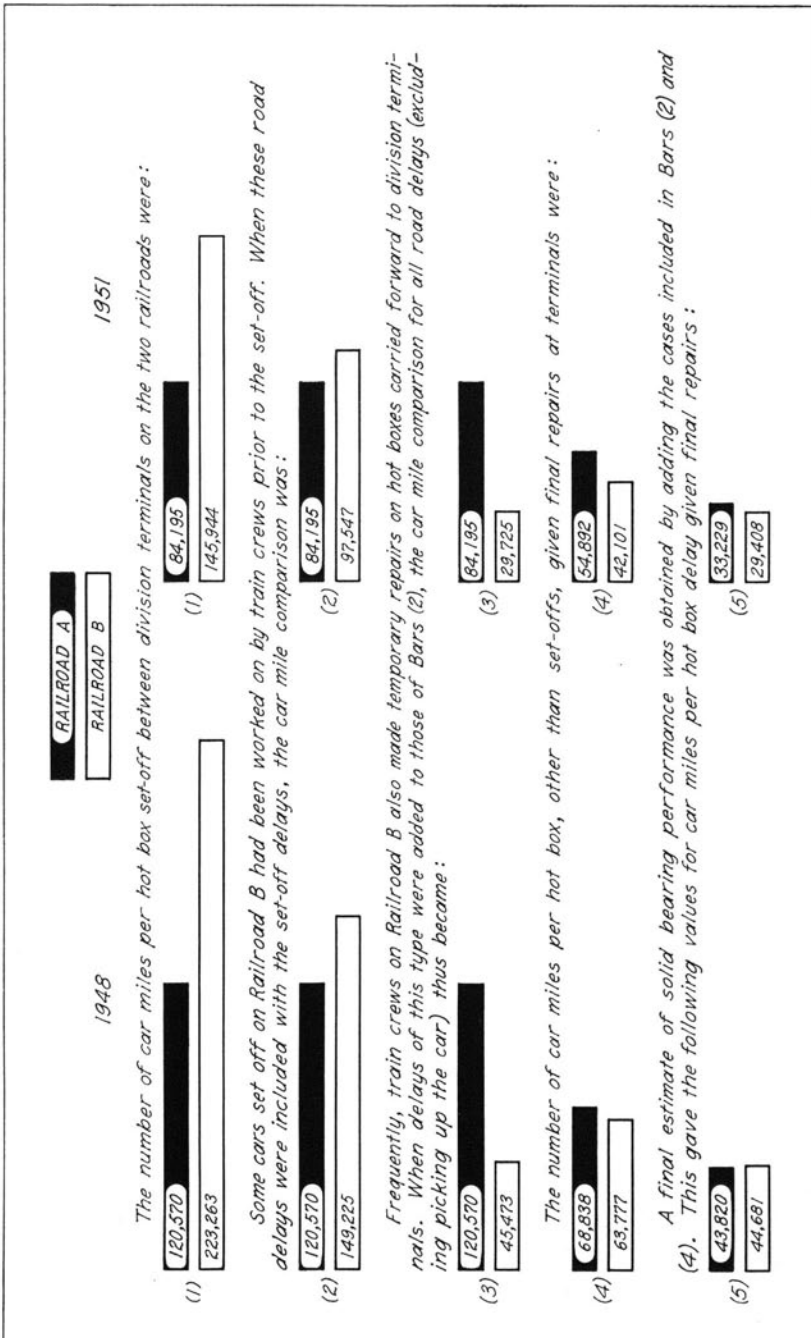

Fig. 3. Solid Bearing Performance, Car Miles Per Hot Box for Railroads A and B, 1948 and 1951

Bars (4) show the car miles per hot box found in the yards. As explained above, many of the hot boxes which were counted as found in the yard on Railroad B had also caused road delays and were therefore included in bars (3).

Bars (5) represent the car miles per hot box included under (2) plus those included under (4). For Railroad A, bars (5) give the car miles per hot box given final repairs. While it has already been mentioned that this figure could not be obtained for Railroad B, bars (5) give a value which should slightly exceed the car miles per hot box given final repairs on Railroad B. It is significant that in any one year the final values obtained in bars (5) were almost identical on both railroads.

By comparing bars (1) and bars (5) it is also seen that the number of car miles per set-off is a poor indication of the total number of service failures.

Another fact made evident in Fig. 3 is that the failure incidence was much higher in 1951 than in 1948. At present no conclusive evidence can be presented to account for this change.

IV. DETERMINED COSTS OF SOLID JOURNAL BEARING OPERATION

Estimates of the cost of solid journal bearing operation on both of the railroads studied were made for the years 1948 and 1951. The estimates exclude cost items of indeterminable size which may be attributed to solid bearing operation. Since the necessary statistics were unavailable, evaluation of these cost items would have made it necessary to conduct extensive special studies which are now economically infeasible. A discussion of these is contained in Chapter V.

Considerable amounts of train and car delays are assignable to solid journal bearing operation. Cost estimates for these rather intangible items are intended to cover total economic costs rather than mere out-of-pocket costs. For this reason the values developed in this chapter are not directly comparable to the values which would be shown in a statement of railway operating expenses.

For comparative purposes, the costs are presented on a cost-per-1000-car-miles basis. Appendix H explains in detail the development of these costs, giving cross reference to supporting data contained in various other appendixes. This chapter is primarily intended to present each class of costs and to demonstrate the importance of the different classes of costs to the total determined costs.

10. Costs of All Types of Hot Boxes

The costs attributable to all types of hot boxes are shown in Tables 3-6, each of which shows the costs for one railroad during a single year. Included in these tables are the costs of train delays, car delays, truck expenses, repair labor and overhead, and materials. The number of axles scrapped due to defects caused by overheating was unknown, and for this reason no charges for axles were included in the hot box costs. All axle costs are included under material costs.

The cost of all types of hot boxes per 1000 car miles is shown to be 41.5 percent higher on Railroad B than on Railroad A in 1948, and 45.5 percent higher in 1951. This sizable difference is largely the result of the different policies of the two railroads regarding the handling of cars developing hot journals between terminals. The policy of Railroad B resulted in more train and car delays and less repair work by repair track

Table 3

Costs of All Types of Hot Boxes per 1000 Car Miles: Railroad A — 1948

	Cut Journals		Rebrass	R and R	Road Rebrass	Total Costs
	1st Axle	2nd Axle, Same Car				
I. *Hot Boxes on Cars Set Off*						
A. Number of Cases	5722	183	628	761	1211	8322 (183)
B. Train and Car Delay Costs						
1. Train Delays	12.812¢		1.406¢	1.704¢	2.712¢	18.634¢
2. Car Delays in Train	5.118		0.562	0.681	1.083	7.444
3. Car Delays on Cars Set Off	10.304		1.131	1.370	1.110	13.915
4. Total Delays (1 + 2 + 3)	28.234		3.099	3.755	4.905	39.993
C. Labor Costs						
5. Road Repairs (Including Transportation)	5.577		0.612	0.742	1.180	8.111
6. Repair Track	6.159	0.123¢	0.071	0.085		6.438
7. Total Labor (5 + 6)	11.736	0.123	0.683	0.827	1.180	14.549
D. Material Costs						
8. Road Repairs	1.872		0.205	0.249	0.362	2.688
9. Repair Track	3.992	0.116	0.187	0.024		4.319
10. Total Material (8 + 9)	5.864	0.116	0.392	0.273	0.362	7.007
E. Total Labor and Material (7 + 10)	17.600	0.239	1.075	1.100	1.542	21.556
F. Total Costs (4 + E)	45.834¢	0.239¢	4.174¢	4.855¢	6.447¢	61.549¢
II. *Other Hot Boxes*						
A. Number of Cases	8099	259	4733	1302		14.393
B. Car Delays at Repair Track	10.035¢		5.232¢	1.439¢		16.706¢
C. Labor Costs	8.717	0.174¢	0.531	0.146		9.568
D. Material Costs	5.650	0.164	1.413	0.041		7.268
E. Total Labor and Material (C + D)	14.367	0.338	1.944	0.187		16.836
F. Total Costs	24.402	0.338	7.176	1.626		33.542
III. *Grand Total Costs*	70.236¢	0.577¢	11.350¢	6.481¢	6.447¢	95.091¢

Table 4

Costs of All Types of Hot Boxes per 1000 Car Miles: Railroad A — 1951

	Cut Journals 1st Axle	Cut Journals 2nd Axle, Same Car	Rebrass	R and R	Road Rebrass	Total Costs
I. *Hot Boxes on Cars Set Off*						
A. Number of Cases	8540	273	937	1135	1808	12,420 (273)
B. Train and Car Delay Costs						
1. Train Delays	18.479¢		2.028¢	2.456¢	3.912¢	26.875¢
2. Car Delays in Train	12.021		1.319	1.597	2.545	17.482
3. Car Delays on Cars Set Off	24.631		2.702	3.274	2.654	33.261
4. Total Delays (1 + 2 + 3)	55.131		6.049	7.327	9.111	77.618
C. Labor Costs						
5. Road Repairs (Including Transportation)	10.004		1.098	1.330	2.118	14.550
6. Repair Track	12.863	0.263¢	0.141	0.171		13.438
7. Total Labor (5 + 6)	22.867	0.263	1.239	1.501	2.118	27.988
D. Material Costs						
8. Road Repairs	3.155		0.346	0.419	0.618	4.538
9. Repair Track	7.337	0.198	0.320	0.077		7.932
10. Total Material (8 + 9)	10.492	0.198	0.666	0.496	0.618	12.470
E. Total Labor and Material (7 + 10)	33.359	0.461	1.905	1.997	2.736	40.458
F. Total Costs (4 + E)	88.490¢	0.461¢	7.954¢	9.324¢	11.847¢	118.076¢
II. *Other Hot Boxes*						
A. Number of Cases	10,566	338	6175	1698		18,777
B. Car Delays at Repair Track	20.985¢		10.931¢	3.006¢		34.922¢
C. Labor Costs	15.914	0.326¢	0.930	0.256		17.426
D. Material Costs	9.078	0.245	2.112	0.114		11.549
E. Total Labor and Material (C + D)	24.992	0.571	3.042	0.370		28.975
F. Total Costs	45.977	0.571	13.973	3.376		63.897
III. *Grand Total Costs*	134.467¢	1.032¢	21.927¢	12.700¢	11.847¢	181.973¢

Table 5

Costs of All Types of Hot Boxes per 1000 Car Miles: Railroad B — 1948

	Prior to Set-off	Cut Journals			Rebrass		R and R	Train Delay		Total Costs
		Road Repair	To Repair Track	2nd Axle, Same Car	Road Rebrass	To Repair Track	To Repair Track	Rebrass	Other Work	
I. *Hot Boxes on Cars Set Off*										
A. Number of Cases										
1. Total Number	1739	263	1713 (119)	100	644	746	20			
2. Road Repairs by Train Crew—Rebrass	743		1635 (93)		550	338				
Other Work	996					408	20			3505 (100)
3. Road Repairs by Repair Track Forces—										
Cut Journals		263								
Rebrass			78 (26)		94					
4. Repairs Made at Repair Track			1713	100		746	20			
B. Train and Car Delay Costs										
5. Train Delays	5.295¢	1.395¢	14.216¢		4.848¢	5.474¢	0.137¢			31.365¢
6. Car Delays in Train	1.474	0.388	3.957		1.349	1.523	0.039			8.730
7. Car Delays on Cars Set Off		0.400	4.835		0.980	2.027	0.054			8.296
8. Total Delays (5 + 6 + 7)	6.769	2.183	23.008		7.177	9.024	0.230			48.391
C. Labor Costs										
9. Road Repairs (Including Transportation)		1.947	0.301		0.272					2.520
10. Repair Track			2.364	0.086¢		0.107	0.003			2.560
11. Total Labor (9 + 10)		1.947	2.665	0.086	0.272	0.107	0.003			5.080
D. Material Costs										
12. Road Repairs	0.328	0.239	0.742		0.249	0.154	0.001			1.713
13. Repair Track			1.558	0.082		0.288	0.001			1.929
14. Total Material (12+13)	0.328	0.239	2.300	0.082	0.249	0.442	0.002			3.642
E. Total Labor and Material (11 + 14)	0.328	2.186	4.965	0.168	0.521	0.549	0.005			8.722
F. Total Costs (8 + E)	7.097¢	4.369¢	27.973¢	0.168¢	7.698¢	9.573¢	0.235¢			57.113¢
II. *Other Hot Boxes*										
A. Number of Cases			5664	289		5612	605	2291	9674	24,135
B. Train and Car Delay Costs										
1. Train Delay Costs								8.336¢	25.177¢	33.513¢
2. Car Delays in Train								2.320	7.007	9.327
3. Car Delays at Repair Track			8.850¢			7.488¢	0.677¢			17.015
4. Total Delays (1 + 2 + 3)			8.850			7.488	0.677	10.656	32.184	59.855
C. Labor Costs			7.817	0.249¢		0.807	0.087			8.960
D. Material Costs			5.150	0.237		2.169	0.027	0.885	0.213	8.681
E. Total Labor and Material (C + D)			12.967	0.486		2.976	0.114	0.885	0.213	17.641
F. Total Costs			21.817	0.486		10.464	0.791	11.541	32.397	77.496
III. *Grand Total Costs*	7.097¢	4.369¢	49.790¢	0.654¢	7.698¢	20.037¢	1.026¢	11.541¢	32.397¢	134.609¢

Table 6

Costs of All Types of Hot Boxes per 1000 Car Miles: Railroad B — 1951

	Prior to Set-off	Cut Journals			Rebrass		R and R	Train Delay		Total Costs
		Road Repair	To Repair Track	2nd Axle, Same Car	Road Rebrass	To Repair Track	To Repair Track	Rebrass	Other Work	
I. *Hot Boxes on Cars Set Off*										
A. Number of Cases										
1. Total Number	2763	414	2696 (189)	158	1065	1173	32			5569 (158)
2. Road Repairs by Train Crew—Rebrass	1181		2573 (148)		917	518				
Other Work	1582					655	32			
3. Road Repairs by Repair Track Forces—										
Cut Journals		414								
Rebrass			123 (41)		148					
4. Repairs Made at Repair Track			2696	158		1173	32			
B. Train and Car Delay Costs										
5. Train Delays	8.425¢	2.199¢	22.415¢		8.047¢	8.604¢	0.220¢			49.910¢
6. Car Delays in Train	3.741	0.976	9.953		3.573	3.820	0.098			22.161
7. Car Delays on Cars Set Off		1.012	12.233		2.603	5.122	0.140			21.110
8. Total Delays (5 + 6 + 7)	12.166	4.187	44.601		14.223	17.546	0.458			93.181¢
C. Labor Costs										
9. Road Repairs (Including Transportation)		4.018	0.593		0.535					5.146
10. Repair Track			5.225	0.196¢		0.227	0.006			5.654
11. Total Labor (9 + 10)		4.018	5.818	0.196	0.535	0.227	0.006			10.800
D. Material Costs										
12. Road Repairs	0.564	0.411	1.248		0.435	0.258	0.001			2.917
13. Repair Track			2.674	0.139		0.480	0.002			3.295
14. Total Material (12 + 13)	0.564	0.411	3.922	0.139	0.435	0.738	0.003			6.212
E. Total Labor and Material (11 + 14)	0.564	4.429	9.740	0.335	0.970	0.965	0.009			17.012
F. Total Costs (8 + E)	12.730¢	8.616¢	54.341¢	0.335¢	15.193¢	18.511¢	0.467¢			110.193¢
II. *Other Hot Boxes*										
A. Number of Cases			8911	454		8831	951	3640	15,371	38,158
B. Train and Car Delay Costs										
1. Train Delay Costs								13.262¢	40.054¢	53.316¢
2. Car Delays in Train								5.888	17.785	23.673
3. Car Delays at Repair Track			22.375¢			18.936¢	1.712¢			43.023
4. Total Delays (1 + 2 + 3)			22.375			18.936	1.712	19.150	57.839	120.012
C. Labor Costs			17.268	0.563¢		1.711	0.184			19.726
D. Material Costs			8.839	0.400		3.611	0.053	1.488	0.427	14.818
E. Total Labor and Material (C + D)			26.107	0.963		5.322	0.237	1.488	0.427	34.544
F. Total Costs			48.482	0.963		24.258	1.949	20.638	58.266	154.556
III. *Grand Total Costs*	12.730¢	8.616¢	102.823¢	1.298¢	15.193¢	42.769¢	2.416¢	20.638¢	58.266¢	264.749¢

forces. The additional train and car delay costs greatly exceeded the reduction in repair track force costs and gave a much higher total cost of hot boxes for Railroad B.

The cost of hot boxes per 1000 car miles is also shown to be much higher for 1951 than for 1948. The increases in 1951 costs over 1948 are 91.4 percent on Railroad A and 96.7 percent on Railroad B. These cost increases were largely due to the combined effects of an approximate 50 percent increase in the failure incidence and substantial increases in the unit costs of car delays and in repair labor and overhead.

Table 7

Costs of Accidents Due to Broken or Burned-Off Journals on Freight Cars

	1948		1951	
I. *Number of Accidents*	*A*	*B*	*A*	*B*
Reportable to ICC	14	19	20	26
Non-reportable to ICC	1	5	5	9
Total	15	24	25	35
System Cars	5	5	7	16
Foreign Cars	10	19	18	19
Train Delays, Hours				
Freight	179.50	215.20	294.50	381.50
Passenger	33.50	31.43	49.33	57.16
Pass. Trns. Detoured	2	0	0	0
II. *Costs*				
Direct Costs of Accidents				
Reportable to ICC*	$94,803	$31,480	$219,074	$169,854
Non-reportable to ICC	35	1,056	1,068	2,250
Damage to Lading	8,498	842	108,547	11,490
Train Delays†				
Freight Car Delays	2,301	2,925	6,193	8,604
Freight Train Delays	8,767	10,510	14,958	19,376
Passenger Train Delays	2,373	2,226	3,750	4,345
Detouring Trains	588	...	...	...
Total Costs	$117,365	$49,039	$353,590	$215,919
Cost Per 1000 Car Miles	11.697¢	6.267¢	33.814¢	26.566¢

* Obtained from ICC records.
† Train Delay Costs
(Train Delays) = Hours Delay × Train Hour Value
(Car Delays) = Days Delay × Ave. No. Cars in Trn. × Car Day Value.

11. Costs of Accidents due to Broken or Burned-Off Journals on Freight Cars

Because of widespread interest in accidents due to burned-off or broken journals, the total costs of such accidents as well as the costs per 1000 car miles are shown in Table 7. Accidents are included which were nonreportable to the ICC. The direct accident costs, which constitute those usually reported to the ICC, include the costs of damage to equipment, damage to ways and structures, and clearing of the wreckage. Indirect costs include the costs of damage to lading, train and car delays, and detouring of trains over foreign lines. In all cases the values used to compute the costs of train delays shown in Table 7 included the crew expenses, since the average train delays caused by the accidents were long and would have resulted in overtime pay.

While Table 7 shows that accident costs on both railroads were much higher in 1951 than in 1948, the number of accidents and the resultant costs experienced on individual railroads fluctuate greatly from year to year. A more significant indication of trends is shown in Fig. 4, where data regarding accidents due to broken or burned-off journals occurring on all Class I railroads are presented for the years 1946-51. (The supporting data for this figure were obtained from the ICC.) Throughout this five-year period the accident costs per 1000 car miles were rising at an ever increasing rate.

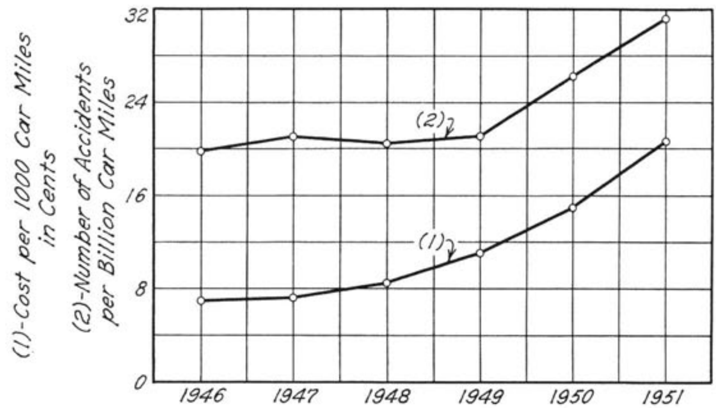

Fig. 4. Accidents Reported to ICC as a Result of Broken or Burned-Off Freight Car Journals for All Class I Railroads, 1946-51

12. Costs of Fires Caused by Hot Boxes

The losses due to fires caused by hot boxes were as follows:

1948	*Number of Fires*	*Total Cost*
Railroad A	10	$15,778.58
Railroad B	6	9,320.59
1951		
Railroad A	16	$11,147.51
Railroad B	10	23,027.81

Included in these figures are the costs of damage to equipment, damage to lading, and damage to ways and structures. These statistics are reported to the AAR Fire Protection and Insurance Section. In Table 8 the costs are reduced to a cost-per-1000-car-mile basis.

13. Costs of Materials

The costs per 1000 car miles of materials which are not otherwise included in the costs of service failures or the costs of routine inspection and lubrication are shown in Table 8. These costs include the net difference in costs of new and scrap materials, storeroom expenses, interest on stock investment, transportation charges and, where involved, local manufacturing labor. The sharp increase in cost shown for Railroad A from 1948 to 1951 was largely due to an increased number of axles and journal bearings being used in 1951.

14. Routine Inspection and Lubrication Costs

The costs of routine inspection and lubrication of solid journal bearings constitute the most important single classification entering into the

Table 8

Determined Costs of Solid Journal Bearing Operation per 1000 Car Miles

	1948		1951	
I. *Service Failure Costs*	*A*	*B*	*A*	*B*
A. Hot Boxes*	95.091¢	134.609¢	181.973¢	264.749¢
B. Accidents†	11.697	6.267	33.814	26.566
C. Fires	1.573	1.191	1.066	2.833
D. Total	108.361	142.067	216.853	294.148
II. *Routine Maintenance Costs*				
A. Material				
1. Journal Bearings	32.873	29.955	50.817	27.028
2. Box Lids	6.874	6.764	7.001	7.128
3. Dust Guards	0.971	1.570	1.994	2.209
4. Dust Guard Plugs	0.114	0.185	0.210	0.568
5. Wedges	0.536	2.676	1.078	1.849
6. Axles	14.796	28.624	23.022	31.836
7. Flame Depressant			0.674	0.335
8. Total (Sum of 1 through 7)	56.164	69.774	84.796	70.953
B. Inspection and Lubrication				
9. Oil	5.306	5.105	3.221	5.613
10. Packing	20.363	17.679	40.972	24.493
11. Labor (Oilers)	154.847	128.279	164.917	179.369
12. Labor (Inspectors)	80.650	66.812	83.674	91.006
13. Car Delays (Rule 66)	50.556	26.431	72.972	46.502
14. Car Delays (Train Yard)	52.387	80.363	87.441	134.136
15. Total (Sum of 9 through 14)	364.109	324.669	453.197	481.119
C. Turning Journals at Wheel Defects	3.933	6.070	4.378	6.952
D. Total	424.206	400.513	542.371	559.024
III. *Grand Total Costs*	532.567¢	542.580¢	759.224¢	853.172

* From Tables 3-6.
† From Table 7.

total determined costs of operation. Included in this category are all costs associated with the day-to-day procedure of inspecting and lubricating car journal boxes in train yards. Also included are all costs associated with the periodical repacking of journal boxes required by AAR Code Rule 66, since this is considered to be a customary procedure conducted in connection with lubrication of the journal boxes. The individual items included are the costs of labor and overhead, materials, and car delays. These values are shown in Table 8 on a cost-per-1000-car-mile basis.

The costs of routine inspection and lubrication were 12.1 percent higher on Railroad A than on Railroad B in 1948, and 6.2 percent higher on Railroad B than on Railroad A in 1951. The increases in 1951 costs over 1948 are 24.4 percent on Railroad A and 48.2 percent on Railroad B. They were due almost entirely to increases in unit costs of labor, car delays, and journal box packing. The large difference in the amount of cost increase on the two railroads is due mainly to differing amounts of change in labor assignments. When the five-day work week for non-operating yard employees took effect in September 1949 the management of Railroad A attempted to prevent large increases in the cost of operation. This was done by keeping approximately the same number of employees and having them work five days a week instead of six or seven. When the five-day work week was introduced on Railroad B the number of employees was increased. As a result the amount of labor assigned to lubrication, measured in man hours per 1000 car miles, was 26.0 percent less in 1951 than in 1948 on Railroad A, and only 2.7 percent less in 1951 than in 1948 on Railroad B.

The importance of the costs of routine inspection and lubrication is emphasized by the fact that they account for between 56.3 percent (Road B, 1951) and 68.3 percent (Road A, 1948) of the total measured costs of solid bearing operation.

15. Costs of Turning Axle Journals and Collars

The labor allowances shown in Rule 107 of the AAR Code for changing wheels include an allowance for the time necessary to turn axle journals and collars. This constitutes a part of normal solid bearing maintenance. The costs for this work on wheels and axles removed due to cut journals have already been charged under the cost of hot boxes and hence are not included here. The costs of this work on wheels and axles changed due to other causes is shown in Table 8.

16. Total Determined Costs of Solid Journal Bearing Operation

The total costs of solid bearing operation which have been determined are shown in Table 8 expressed in terms of 1000 car miles. Thus, Table 8 constitutes a summary of the main results of this investigation. The relative importance of the classes of costs entering into the total determined costs is further illustrated in Fig. 5.

Though bearing service failures resulting in hot boxes, accidents, and fires are matters of great interest and concern to railway officials, such service failures do not cause the majority of expenses which are attributable to solid bearings. In the same connection, however, it should be noted that the proportion of determined costs due to service failures was higher in 1951 than in 1948 on both railroads studied. On Railroad A this proportion increased from 20.4 percent to 28.6 percent, and on Railroad B from 26.2 percent to 34.5 percent.

The total determined costs per 1000 car miles were 1.9 percent higher on Railroad B than on Railroad A in 1948, and 12.4 percent higher in

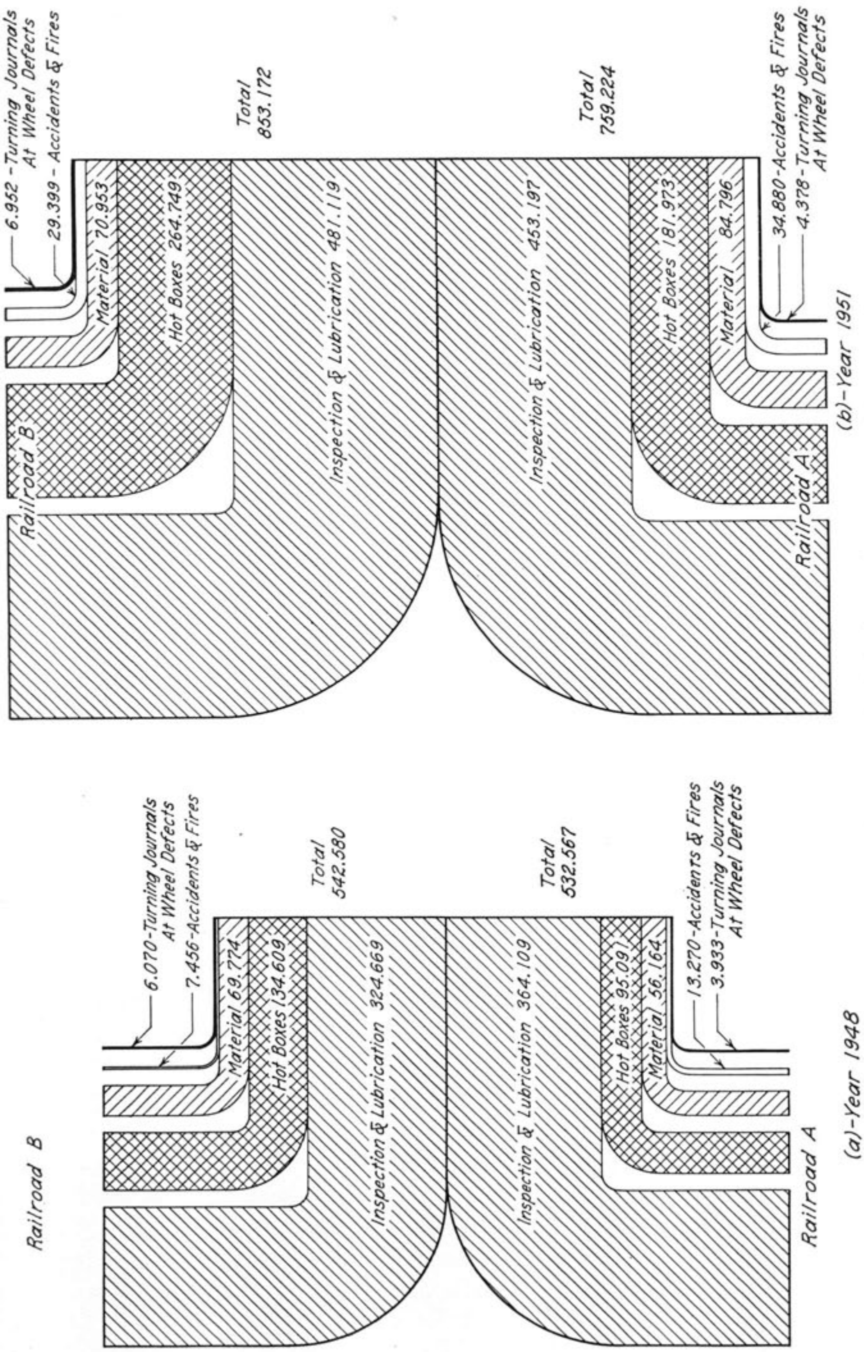

Fig. 5. Flow Chart Showing Relation of Individual Classes of Costs to Total Determined Costs, Expressed as Cents Per 1000 Car Miles

1951. The large difference in 1951 is almost entirely the result of using different amounts of bearing inspection and lubrication labor, as discussed in Section 14.

The increases in 1951 costs over 1948 are 42.6 percent on Railroad A and 57.2 percent on Railroad B. The immediate causes of the most important cost increases are discussed in Sections 10, 13, and 14. The main reason for the differences in the amount of increase on the two railroads is also the varying extents to which labor was used on bearing inspection and lubrication.

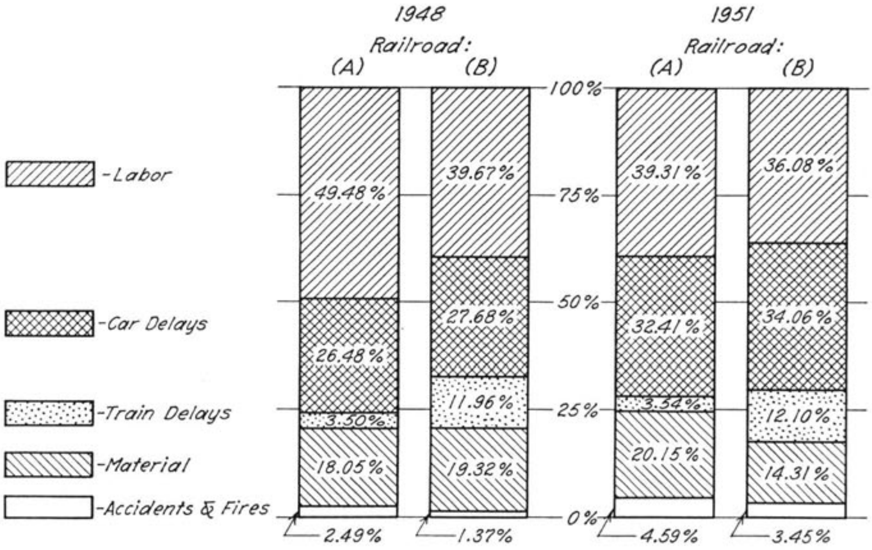

Fig. 6. Percentage Distribution of Determined Costs of Solid Journal Bearing Operation

Figure 6 shows percentage distributions of the determined costs by divisions of costs due to labor, materials, car delays, train delays, and accidents and fires. The costs of train and car delays occurring in conjunction with accidents are included in the costs of accidents and fires, and not with the train and car delay percentages shown. The percentage of costs due to train and car delays in accidents is small (from 0.25 to 0.46 percent) and including them in the accident costs does not significantly alter the rest of the cost distribution. Included in the costs due to labor are the costs of truck mileage associated with temporary repairs to hot boxes. This cost accounts for a very small percentage of the total determined costs — approximately 0.56 and 0.07 percent for roads A and B respectively.

The diagram in Fig. 6 for 1948, when the total determined costs on both railroads were almost exactly the same per 1000 car miles, demonstrates that the lower labor costs on Railroad B were almost entirely offset by higher train delay costs. In the diagram for 1951, this relationship becomes somewhat altered. However, the total determined costs were not so directly comparable in 1951, for reasons already discussed. The percentage distributions for Railroad A show relatively large changes between 1948 and 1951. These changes are mainly due to reduced amounts of labor assigned to bearing inspection and lubrication in 1951.

V. UNDETERMINED COSTS OF SOLID JOURNAL BEARING OPERATION

17. Importance of Undetermined Costs

There are certain costs attributable to solid bearings which generally are conceded to exist but which are very hard to measure accurately. The most important of these are discussed in sections which follow, some of which point out that certain portions of individual important railway operating expenses result from special characteristics of solid bearings. It may be argued that only very small portions of these expenses are due to solid bearing characteristics. This in itself may be true, but what should not be overlooked is that the expenses involved are in themselves very large. The costs of these expenses assigned and apportioned to freight service, expressed on a cost-per-1000-car-mile basis, for all Class I line-haul steam railways were as follows in the years given:

	1948	*1950**
Yard Fuel (ICC Acc'ts. 382,383, and 384)	287.7¢	208.6¢
Train Fuel (ICC Acc'ts. 394,395, and 396)	1563.4	1215.4
Loss and Damage (ICC Acct. 418)	404.6	270.7
Total	2255.7¢	1694.7¢

If it could be conclusively demonstrated that as small a portion as 5 percent of the total cost shown above was due to solid bearing characteristics, it would increase the determined costs previously developed between 10 and 21 percent.

In the discussions which follow, wherever portions of fuel expenses are attributed to solid journal bearing operations, the assumption is inherently made that train speed and acceleration are held constant. In connection with fuel expenses it should be pointed out that no attempt has been made to consider fuel costs which would be associated with ordinary operation of a bearing in any application. Only those fuel costs definitely associated with the special characteristics of solid type bearings as related to railway freight car applications have been considered.

18. Fuel Costs Arising from Special Characteristics of Solid Journal Bearings

The conventional solid bearing assembly has a relatively high running temperature when stable temperature conditions are reached. When trains are started out of terminals, the cars have usually been standing

* At the date of writing, 1950 statistics are the latest available.

for a period of time. During this time, the temperature of the bearing assemblies of the cars has been decreasing and approaching that of the atmosphere. As the train leaves the terminal, the temperature of the bearing assemblies increases, because of the heat developed by the bearing friction. The temperature continues to increase until the heat developed in the bearing equals the heat dissipated; the bearing temperature then remains relatively constant, provided that train speed does not fluctuate greatly. During the period in which the bearing assemblies are warming up, the viscosity of the oil is higher than it is after stable running conditions have been reached. Schmidt(8)* and others(9) found that train resistance was abnormally high during this warming up period, and Schmidt concluded "that this difference in resistance was due to variations in the conditions of lubrication of the car journals, and that such variations were chiefly caused by variations in journal temperature." Where the train speeds were below 40 mph and the temperature was above 40 F, distances of 8-10 miles were required to establish uniform values of train resistance.

The conditions discussed above would also be present, though to a lesser degree, whenever trains are stopped between terminals. The amount of increase in train resistance which results from such a stop would be a function of the decrease in temperature of the bearing assemblies, which, in turn, would be mainly a function of the duration of the stop and of the outside temperature.

During the warming up of the car bearings, fuel is consumed in excess of that which would be consumed if stable bearing temperatures and accompanying lower train resistances were being obtained. While this is a fairly important factor in fuel consumption of road locomotives, it should be even more important in determining the fuel consumption of yard locomotives; in yard operation cars are usually moved short distances after standing for relatively long periods of time. Available information supports these conclusions but is not extensive enough to permit quantitative estimates of the excess fuel consumed, determination of which would require extensive laboratory or field research. Because the phenomena are transitory and the number of variables which might influence results is great, such a research program would be costly and difficult to devise, and is definitely beyond the scope of the present work.

Under conditions of winter temperatures, the effects previously discussed are even further intensified. Schmidt found that at 15 mph a distance of 35 miles from the starting terminal was required before a uniform value of train resistance was obtained under low-temperature conditions. This may be compared with the distances of 8-10 miles when the temperature was above 40 F.

* Superscript numbers in parentheses refer to the correspondingly numbered entries in the References.

Furthermore, Schmidt stated[10] that stable train resistance is higher during cold weather than during warm; he attributed this to higher bearing friction in winter weather. The reasoning is that in order to maintain a certain rate of heat dissipation from the journal box the temperature difference between the bearing and the outside air must remain essentially constant. In cold weather the journal temperature may therefore be lower and the minimum viscosity of the oil may be greater than in warm weather.

It might be expected that locomotive fuel consumption would be higher in winter than in summer weather, and ordinarily it is. During studies conducted in an attempt to isolate the influence of temperature from other variables affecting fuel consumption, the performance of a group of 15 four-unit 5400 hp diesel-electric locomotives on Railroad B was analyzed. These locomotives were not equipped with train heating boilers. During the two-year period (1948 and 1949) studied, 99.56 percent of the mileage run by these 15 locomotives was in road freight service. They accounted for 37.8 percent of the freight train miles and 51.6 percent of the gross ton miles produced by disel-electric locomotives on Railroad B.

The data available for this class of locomotives were expressed on a monthly basis. They included (1) gallons of fuel oil consumed, (2) gross ton miles hauled, and (3) road freight locomotive miles. Data regarding monthly minimum temperatures for the area in which the locomotives operated were computed from climatological records of the United States Weather Bureau. The locomotives studied were operated over long distances, a fact that necessitated the procurement of temperature data for a large area.

From the basic data obtained, three variables were derived for use in a multiple correlation analysis:*

A — gallons of fuel oil consumed per 1000 gross ton miles. This was the dependent variable of the multiple correlation analysis — i.e., the variable whose fluctuations were to be explained.

* Multiple correlation is a statistical method for measuring the extent to which one variable, the "dependent variable" is influenced by a group of other variables. The latter are denoted as the "independent variables" inasmuch as these are presumed to largely determine the dependent variable and are independent of it. The result of the analysis is an equation expressing the dependent variable as a function of the independent variables, and hence showing the effect on the dependent variable of a given change in any of the independent variables.

It is different from usual engineering methods in that the influence of simultaneous variations in two or more independent variables can be determined and segregated by merely analyzing records of former experiences. Engineering methods might determine the influence of one independent variable from 5 or more controlled test observations (all other independent variables held constant). Multiple correlation analysis can determine the effects of two or more independent variables from preferably 30 or more sets of observations (each including values for all variables being considered) of uncontrolled conditions.

B — gross ton miles per road freight locomotive mile. More simply stated, this represents average train loading. For the period studied, this variable ranged in value from 3500 — 4940 tons.

C — average monthly minimum temperature, which had a range from −5.6 to 56.8 F.

Table 9

Comparison of Actual and Estimated Fuel Consumption of 5400 HP Diesel-Electric Locomotives

Year	Month	Fuel Consumption *Gal. per 1000 Gross Ton Miles* Actual (1)	Estimated (2)	Percent Error $100 \times \frac{(1) - (2)}{1}$
1948	J	1.82	1.86	−2.20
	F	1.79	1.84	−2.79
	M	1.74	1.75	−0.57
	A	1.63	1.67	−2.45
	M	1.60	1.67	−4.38
	J	1.78	1.77	0.56
	J	1.73	1.68	2.89
	A	1.67	1.72	−2.99
	S	1.84	1.74	5.43
	O	1.89	1.73	8.46
	N	1.72	1.79	−4.07
	D	2.00	1.89	5.50
1949	J	2.04	1.95	4.41
	F	2.01	2.03	−1.00
	M	1.68	1.77	−5.36
	A	1.43	1.48	−3.50
	M	1.52	1.52	0.00
	J	1.52	1.46	3.95
	J	1.60	1.57	1.88
	A	1.70	1.65	2.94
	S	1.72	1.80	−4.65
	O	1.71	1.73	−1.17
	N	1.81	1.83	−1.10
	D	1.86	1.87	−0.54

The results of the multiple correlation analysis indicated that 80 percent of the variation in fuel consumption was accounted for by the combined effect of temperature and load. The results may be expressed in equation form as follows:

$$A = 3.256 - 0.00173\ C - 0.000349\ B \qquad (1)$$

Use of this equation should not be extended to include values of the independent variables outside of the ranges studied. Estimates of fuel consumption prepared from this equation are compared with actual values of fuel consumption in Table 9. In all but four cases the estimates are less than 5 percent in error. The maximum error is 8.5 percent, and the average absolute error is 3.0 percent.

When the value of B is held constant at 4200 tons, which was approximately the average value of B for the period studied, Eq. (1) takes a special form:

$$A = 1.790 - 0.00173\ C \qquad (2)$$

From Eq. (2), Fig. 7 was prepared. It shows the percent increase in fuel consumption relative to that at a value of C equal to 55 F as the average monthly minimum temperature decreases below 55 F.

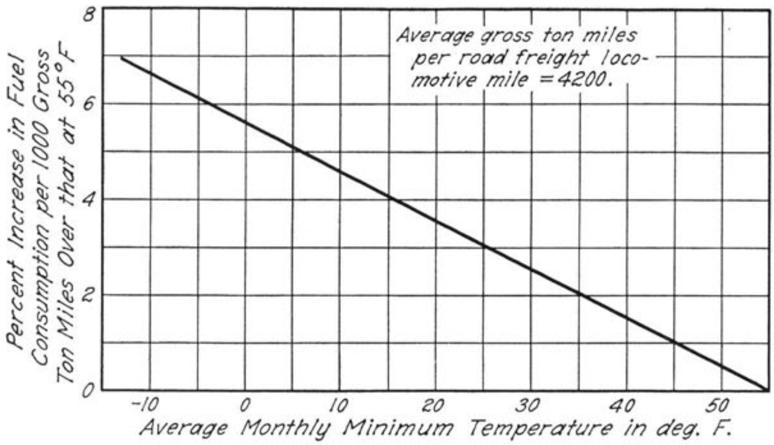

Fig. 7. Effect of Temperature on Diesel Locomotive Fuel Consumption from a Study of 15 Four-Unit 5400 HP Locomotives on Railroad B

In Fig. 7, as the average monthly minimum temperature decreases from 55 F to 20 F the fuel consumption is shown to increase 3.57 percent. Test data(12) obtained on a diesel locomotive of the same basic design showed that with fuel consumption held constant, power output increased approximately 3.25 percent when a similar decrease in air temperature was experienced. Considered together, these two values support the conclusion that as the above-mentioned temperature decrease took place, the actual power consumed per 1000 gross ton miles increased approximately 6.92 percent.* Generally, the same type of relation would be found for other values of temperature reduction below 55 F — namely, that the percent increase in actual power consumption would exceed the percent increase in fuel consumption shown in Fig. 7. This result is due to the fact that the efficiency of the diesel-electric locomotive increases slightly

* Let

From test of diesel engine
- P_1 = power output at 55F with fuel consumption F_1
- P_2 = power output at 20F with fuel consumption F_1
- $P_2 = 1.0325\ P_1$

P_3 = power output at 20F with fuel consumption F_2

From multiple correlation analysis
- $F_2 = 1.0357\ F_1$

Then

$$P_3 = P_2 \times F_2/F_1$$
$$= 1.0325\ P_1 \times 1.0357\ F_1/F_1$$
$$= 1.0692\ P_1$$

with decreasing temperature. However, quantitative data for the change in locomotive efficiency with change in temperature are not available for the entire range of temperatures studied. The lack of such data prevents the conversion of the data of Fig. 7 into a series of values illustrating the increase in actual power consumption with decreasing temperature.

It must not be immediately concluded that all of the increase in power consumption associated with decreasing temperature may be attributed to increased resistance of solid journal bearings, since data regarding other variables influencing power consumption were not available for use in the multiple-correlation analysis. Among the missing data was information pertaining to the important variable of train speed, which was not available for individual groups of locomotives. However, data for all diesel-electric freight service on Railroad B showed that speed was approximately 1.8 percent lower in the November-through-March period than in the April-through-October period for the years studied. If train speed for the 5400 hp locomotives followed this same trend, variations in speed probably did not largely influence results, and — possibly even more pertinent — also would have tended to cause slightly lower power consumption during the winter months.

Another variable for which no reliable data were available was the amount of power consumed due to accumulation of snow, sleet, and ice on the tracks. If this was important in determining power consumption, a change in the characteristic increase of fuel consumption with decreasing temperature might be expected at about 32 F. However, the relationship with temperature was linear throughout the range studied and showed no pronounced changes in certain locations.

Locomotive utilization might possibly be another variable affecting fuel consumption. Data regarding this variable, expressed in percent of total hours utilized, were not available. The locomotive miles per locomotive day, however, were substantially equal for both winter and summer months. There may be still other variables, such as formation of ice on brake rigging, which affect fuel consumption to some degree; again data concerning any of these were not available. Considering the close relation between estimated and actual fuel consumption shown in Fig. 7, the effects of such additional variables would not appear to have been of great importance. The foregoing discussion of pertinent variables indicates that a large portion of the increase in power consumption with decreasing temperature was probably due to the increased resistance of solid journal bearings.

The amount of fuel consumption on entire railroad systems which actually results from increased resistance of solid bearings in winter weather is still a matter of conjecture. To derive reasonable estimates would require further information regarding locomotive efficiency and power consumption due to other effects previously discussed. This information could be obtained only by very detailed, thorough, and costly technical investigations which are beyond the scope of the present bulletin.

19. Costs of Tonnage Reductions Due to Characteristics of Solid Journal Bearings

It has been common practice on railroads to reduce the tonnage ratings of locomotives during cold weather. On some railroads, definite reductions are established for various temperature ranges, and such information is contained in operating time tables. Other railroads leave tonnage reductions up to the discretion of local officials. The latter situation prevailed on Railroads A and B, which made it impossible to get reliable quantitative information regarding tonnage reductions.

One of the reasons for reducing tonnage during cold weather is increased resistance of solid journal bearings. There are several other conditions which have led to tonnage reductions in cold weather. In the past, reduced power output of steam locomotives in cold weather required some tonnage reduction, but this factor has largely been eliminated by widespread use of diesel-electric locomotives. Diesels have tractive effort ratings determined largely by the current capacities of the traction motors. Ordinarily, no distinction is made between amperage capacity in the winter and in the summer, although it conceivably might be slightly higher in the winter. Recently, severe leakage of air from car brake equipment during cold weather has limited train length, and consequently train tonnage. Steps are now being taken to prevent this air leakage and remove this cause of tonnage reductions. Other conditions, such as reduction of adhesion between locomotive driving wheels and the rail, necessity for running through snow, and the drag created by ice forming on brake rigging, are all factors which might require reduction in train tonnage during cold weather. Because of lack of quantitative information on the influence of these other variables, it is not known how much of the reduction in tonnage ratings might be attributed to the increased bearing resistance.

It is known that the percentage of tonnage reductions for a given decrease in temperature is usually greater on operating districts with light ruling grades than those on districts with heavy grades. The resistance due to grades does not change with temperature, and on heavy grades this resistance forms a larger part of the total train resistance than when grades are light. Therefore, on low grade divisions the portion of total train resistance subject to change with temperature is greater, and consequently the percentage of change in tonnage ratings with temperature is also greater. These known facts also imply that variables affecting train resistance are more important in determining tonnage reductions than variables affecting available locomotive tractive effort, since if the latter variables were more important, the percentage of reduction in tonnage ratings would tend to be influenced less by variation in grade conditions on different divisions.

It is also known that the proximity of operating stops and division terminals to ruling grades on a division has an important bearing on the amount of reduction in tonnage which is necessary in cold weather. The closer the operating stops or division terminals are to the ruling grades, the greater the reduction in tonnage. To illustrate how stops between terminals may influence railroad operations during winter weather, the difficulties which resulted from 11 such stops are reported as stated on train delay reports of Division I of Railroad B. Following these 11 stops, an average delay of 78.5 minutes was occasioned in attempting to restart the train. The mean daily temperature which prevailed ranged from –14.2 F to 17.7 F, with an average of –2.4 F. While it is generally considered undesirable to have the ruling grade for a division located immediately outside the division terminals, the existence of such a condition is rather common. This was the case in nine separate locations on Railroad B. It is known that at one of these points helper service was provided leaving the yard as standard practice during the winter to avoid large reductions in train tonnage. Winter reductions in train tonnage due to the location of stops and terminals close to ruling grades are largely attributable to the highly increased train resistance which is experienced in the first few miles of operation after the journal bearing assemblies on the cars have been allowed to cool and approach atmospheric temperature conditions. Where large tonnage reductions are made for these reasons during the winter, the same effects have probably exerted some influence, but to a lesser degree, in limiting the tonnage ratings established for summer weather conditions.

Essentially, tonnage limitations result in the costs arising from running additional train miles to handle a given amount of traffic. If the amount of tonnage limitations imposed by solid journal bearings were determinable, the costs of such limitations would include the resulting excess in train crew expenses, locomotive repair expenses, and other expenses affected by the number of train miles. The expenses due to helper service which is provided to maintain train tonnage, where such helper service is attributable to characteristics of solid bearings, should also be included. It is possible that, on railroads where peak traffic occurs during winter months, tonnage limitations that were imposed by solid bearings would also result in the costs of ownership of a larger number of locomotives than would be required if such limitations were removed.

20. Costs of Loss and Damage Attributable to Solid Journal Bearing Operation

In the five-year period 1946 to 1950, member roads of the AAR paid \$554,708,242 for loss and damage claims made against them by shippers. Large as this sum is, it does not include any of the considerable expenses which actually result from the same cause as did the loss or damage to lading, such as expenses of equipment repairs. Another factor not reflected in the above sum is the amount of customer dissatisfaction and diversion of traffic to other forms of transportation which may result from loss and damage of shipment.

Of the total amount shown, 68.71 percent was due to damage claims classified under "Unlocated Damage," "Improper Handling Damage," and "Concealed Damage." Damage claims so classified arise largely from excessive impacts being transmitted to the car lading. These impacts may occur in conjunction with yard switching, serial starting of trains, brake applications in trains, running over a rolling profile, or rough riding of cars which have little or no control of the vertical action of the truck springs.

That portion of the damage claim bill due to impacts received in rough riding of cars is definitely not attributable to solid journal bearing operation. The impacts, and thus the damage claims, received in the other cases mentioned are in part due, directly or indirectly, to the amount of free slack which is allowed in the couplings of the cars. By free slack is meant the amount of relative movement which can exist between cars with no resisting force being developed by the action of the draft gears. The amount of free slack which is present probably averages between 3 and 6 in. per car. While a certain amount of free slack results from wear, a large part of it is provided to aid in the starting of long trains by the process of bunching slack and then starting the cars individually. This practice has been customary because of the high starting resistance offered by cars with solid journal bearings, which, on level track, is in the neighborhood of 40 lb/ton. Wherever ruling grades are less than about 1.6 percent, this means that it would be more difficult for a locomotive to start the entire train at once on level track than it would be for the locomotive to later haul the same train over the ruling grade. Needless to say, the majority of ruling grades are much less than 1.6 percent; hence the general necessity of bunching slack to start trains. In recent years diesel-electric locomotives have reduced somewhat the necessity for bunching slack to start, because of their tremendous starting tractive effort. However, the margin between the starting tractive effort and the continuous tractive effort of these locomotives has been constantly diminishing as improved traction motors are developed. If the later models of diesels operate with trains of tonnage at or near the rating of the locomotive, the necessity for bunching slack to start remains. Since it is highly probable that almost every railroad in the country has situations where it is prudent to operate with trains of locomotive tonnage rating, the diesel locomotive cannot be regarded as a device which eliminates the need for putting free slack into the cars. It is probable that free slack will be provided as long as the high starting resistance characteristic of railway freight cars prevails.

Free slack results in the possibility of having, at various points in a train, independent and different rates of acceleration or deceleration. Such a situation results in serial impacts within the train. These events frequently occur during starting, during brake applications, and while running over a rolling profile. It may be argued that the severity of the impacts which occur in these cases does not approach those which occur in yard switching operation. Although this may be true, it does not necessarily follow that the train service impacts do not bear much of the responsibility for damage claims. The reason for this is that the number of impacts is frequently just as important in causing damage as is the severity of any single impact. Each impact serves to loosen up the load and increase susceptibility to damage in the case of later more severe impacts. Therefore, inasmuch as free slack results in innumerable train service impacts, it bears a large portion of the responsibility for damage claims, but how much responsibility it is not possible to determine at the present time.

It has been implied that a large amount of damage occurs in yard switching operations. It might be thought that free slack has little effect on the amount of impact which the lading receives during switching, since this is mainly a function of car weight, coupling speeds, and draft gear capacities. However, free slack of itself places limitations on the energy absorption capacity of conventional draft gears, and it is when draft gear absorbing capacity is exceeded that impact energy is transmitted to the lading. The travel allowed for draft gears ranges from $2\frac{5}{8}$ in. to $3\frac{1}{4}$ in. The energy absorption capacity of conventional draft gears within this travel has about reached the maximum which can be attained without using excessively high force levels. If free slack, and the undesirable effects which it introduces in train service, could be reduced or eliminated, it is probable that allowable draft gear travel would be substantially increased. This would yield greater energy absorbing capacity and result in fewer impacts being transmitted to the lading during switching, which in turn would reduce lading damage. Since free slack places limitations on allowable draft gear travel, it thus bears an indirect responsibility for many of the impacts delivered to lading, and in turn, much of the damage which occurs during switching operations. Again, exact evaluation is impossible.

In the five-year period for which the aggregate loss and damage claim bill was given at the beginning of this section, 5.30 percent of this sum was due to delay in movement or delivery of freight, or delays due to car defects. It would seem reasonable to assume that the large amounts of train delay due to hot boxes might occasionally cause trains to miss connections and result in the filing of claims due to delay. It also seems reasonable to assume that claims due to delay might be filed where individual shipments were delayed enroute because the car involved had to be repaired for a hot box. An attempt was made to get the facts in the situation from two private car owners and from the Claim Department of Railroad A. It was found that the manner in which claims were filed in these organizations makes it impracticable to determine the actual cause of claims due to delay. It was also found that cars carrying perishable shipments received special attention, so that costs incurred from mechanical failures on such cars would show up in higher operating costs rather than in damage claims. A special study was made on Railroad A of 400 cars having mechanical failures, the majority of which were hot boxes. Of the 400 cars, only one had a claim filed with Railroad A. The other 399 either had no claims filed against them or the claims had been paid by some other railroad. It would seem therefore, that costs of claims due to delays resulting from hot boxes is of negligible importance in costs of solid bearing operation.

The investigation also made evident that the value of claims due to delay would be a very poor measure of the economic effects of delays of railroad shipments. In some cases, when industrial consignees receive notice that shipments will be delayed they curtail their operations by instructing workers not to report for work until the shipments arrive, and claims are not filed; in these cases the losses of the workers are not reflected in damage claims. In the event of late delivery, consignees of perishable freight file claims only when the market price drops between the time of expected and actual delivery. Therefore, the claims paid due to delay are not a true indication of the total costs which arise from delays to railroad shipments.

21. Costs of Draft Gear and Coupler Maintenance Due to Characteristics of Solid Journal Bearings

Both the high starting resistance of solid journal bearings and the accompanying free slack provided in the couplers result in large shock loadings of the couplers and draft gears. If cars did not have high starting resistance or large amounts of free slack, these shock loadings would be greatly reduced, particularly when the coupler is loaded in tension. It is thus reasonable to assume that some of the present costs of maintaining couplers and draft gears might be attributable to solid journal bearing characteristics, but the exact amount is indeterminable.

22. Other Intangible Costs

Solid journal bearing service failures result in much interruption of road service. According to the sample studies (Appendix C) of freight train delays due to mechanical failures of car equipment, the percentage of such delay due to hot boxes was 73.72 on Railroad A and 79.28 on Railroad B. This preponderance of road failures carried over to a somewhat lessened degree into domination of work done at several on-line repair tracks.

In large originating or classification yards, most of the repair work is occasioned by normal wear and usage of parts, and most of this type of work is done at these points. At smaller on-line repair tracks, most of the defects corrected are characterized by a relatively sudden failure of some part, exemplified by the hot box. It was found that as many as half of the cars repaired at such points needed repairs because of hot journal bearings. The large seasonal variations in hot box occurrence naturally result in large seasonal variations in the number of hot boxes repaired. Seasonal variations are more prominent in this defect than in any other defects which occur in sizable numbers. Seasonal variations in hot box occurrence therefore affect substantially the work done at smaller on-line repair tracks. If enough men are stationed at such points to handle the repairs to cars for hot boxes and still give proper attention to other defects during the "hot box season" there will be a large loss in productivity at these points during seasons when the hot boxes are not prevalent unless other work is scheduled to keep the workers busy. Excess labor costs resulting from the foregoing conditions are chargeable to solid journal bearing operation.

Bearing service failures and the needs for every day lubrication attention are in a large degree responsible for certain uneconomical characteristics of present car repair and inspection practices. Numerous small car repair points are in existence mainly because of bearing repair requirements, although several other defects of a lesser nature are corrected at these points. Slow movement of trains through intermediate terminals is common, and is partly due to the constant bearing inspection which is necessary to maintain safety. It would be difficult to estimate costs due to these car repair and inspection practices and therefore such estimates have not been made.

Another possible cost item which was not fully investigated is the cost of injuries to persons incurred either in connection with inspection, repair, and lubrication of car journal boxes or in journal bearing accidents.

VI. INVESTIGATION OF VARIOUS FACTORS INFLUENCING THE DEVELOPMENT OF HOT BOXES

23. Atmospheric Temperature

(a) Daily Temperature Variations — The effect of daily temperature variations on the development of hot boxes has been investigated by the use of two different approaches.

The first utilized multiple correlation analysis. Daily figures were obtained on (1) the number of hot boxes set out and found in the yard on Division I of Railroad A during **1948** and on (**2**) temperature, rainfall, and number of loaded and empty cars passing over the division. Correlation of hot boxes with these other variables revealed that only temperature exerts any discernible effect. It was found that when the mean daily temperature was from **10** to **35** F, variations in temperature explained **40** percent of the daily fluctuations in the total number of hot boxes. In this temperature range, a drop in temperature led to a rise in the number of hot boxes. From **35** to **80** F, no significant correlation could be established between daily hot boxes and daily temperature. What this indicates is that temperatures from **10** to **35** F do and temperatures from **35** to **80** F do not have *immediate* effects on the development of hot boxes. In general, therefore, unknown influences — factors for which data were not obtainable — appear to have played a dominant role in the daily fluctuations in the number of hot boxes.

The second approach involved the use of a method which is more fallible but which was the only one permitted by the available data. What was desired was a means for grouping daily information concerning hot boxes and temperature to overcome the effects of erratic day-to-day fluctuations in the number of hot boxes, and at the same time some means for expressing hot boxes as a function of traffic. The method evolved for accomplishing the desired results is explained in the discussion which follows.

The influence of daily temperature variations on hot box occurrence was investigated on three northern divisions of Railroad A and all nine divisions of Railroad B. The daily temperature records of a central point on each division were investigated to find the number of days of the year when the average of the daily maximum and daily minimum temperature was within given temperature ranges. The number of hot boxes set out on the division on corresponding days was obtained from monthly hot box reports. Railroad reports furnished monthly figures for car miles by division. The average daily car miles on each division during the month was obtained by dividing the total car miles for the month by the number of days in the month.

The temperature data for each division were grouped to show the number of days in each month when the temperature was in a given range. It was then possible to estimate the number of car miles on each division in a given temperature range for a given month in the following manner:

Car Miles in Temp. Range 0.1 to 10.0 F =

(Av. Daily Car Miles) × (Days in Temp. range 0.1 to 10.0 F)

A summation of figures so obtained gave an estimate of the total car miles run in each temperature range. While the limitation of this means of estimating car miles run in each temperature range is obvious, it is believed that in most cases errors in the final results are small. Large deviations from the average daily car miles for the month which may have existed on individual days would not necessarily introduce sizable errors, since a large deficiency in car miles on one day in a given temperature range may have been overcome by a large excess in car miles on a second day in the same range during the month.

The temperature, set-off, and car mile data were used to prepare values for the hot box set-offs per million car miles in various temperature ranges. These values are illustrated in Fig. 8.

The hot box set-offs per million car miles is merely an inverse function of car miles per set-off. While a rise in the car miles per set-off indicates an improvement in bearing performance, a rise in the hot box set-offs per million car miles indicates an increase in the number of hot boxes incurred in conjunction with the same number of car miles.

The main purpose of Fig. 8 is to show the similarity of the influence of temperature on the set-off performance of the two railroads rather than to compare set-off performance in any one temperature range for the two railroads, since (as explained in Chapter III) differences in policy on the two railroads influence the relative number of set-offs. It is important to note that Fig. 8 shows only average relationships and does not indicate the variations about the average which occurred on individual days. Figure 8 shows that on both Railroads A and B the number of hot box set-offs per million car miles reached a minimum value in the temperature range 30-40 F. Below 30 F a decrease in temperature was accompanied in both cases by an increase in the relative number of set-offs. From 40 to 70 F an increase in temperatures was accompanied in both cases by an increase in the relative number of set-offs. A reduction in the number of set-offs occurred when the temperature was above 70 F on Railroad B. A similar reduction occurred on Divisions 1, 2, and 3 of Railroad A when the temperature was above 80 F.

This reduction in the number of set-offs which occurred above certain temperature ranges may have been due to other outside influences. In

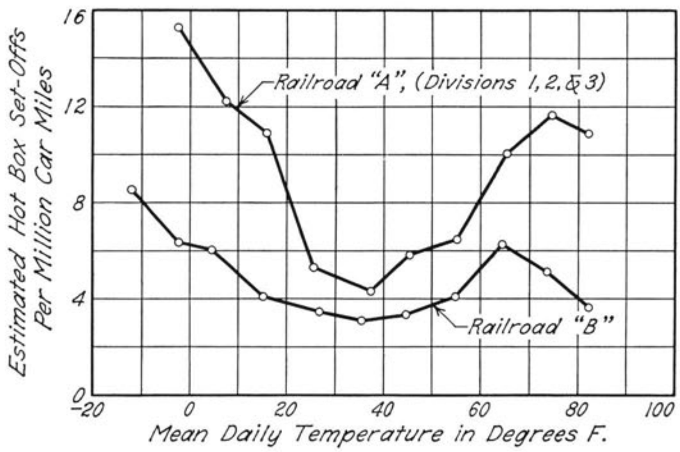

Fig. 8. Relation Between Hot Box Set-Offs Per Million Car Miles and Temperature, Railroads A and B, 1948

the spring season both railroads experienced increases in traffic in commodities which are used in construction work. In most cases cars loaded with these commodities originated at small way stations where no inspection was made of the car journal boxes. When daily temperatures increased during the late spring, a considerable number of cars loaded with these commodities were set off with hot boxes before passing through the first inspection terminal. This situation usually resulted in a study of lubrication and inspection labor assignments by local officials. In many cases the distribution of labor assignments could be changed to obtain better set-off performance. The change in labor assignment usually took the form of moving an inspector to a point where large numbers of heavy loads originated, where he would inspect cars prior to loading and movement in trains. Changes in labor assignments of this type usually took place by mid-July and ordinarily resulted in material improvement of set-off performance. During the very hot weather of July, August, and September, the set-off performance of cars loaded at on-line locations was thus, in many cases, greatly improved over that which existed in the slightly cooler weather of May and June. It is therefore believed that changes in the effectiveness of lubrication attention influenced the set-off performance obtained in the upper temperature ranges shown in Fig. 8.

(b) Weekly Temperature Variations — Another and possibly more valid means of accomplishing almost the same results obtained by the second approach to analyzing effects of daily temperature variations is to combine daily figures into weekly averages and thereby to reduce the relative importance of erratic fluctuations that may be due to the use of an unduly small time unit. This method was used in a multiple correlation analysis of weekly variations in hot boxes on Division I of Railroad A for 1948. The dependent variable in this analysis of weekly fluctuations was the ratio of total hot boxes to total cars handled.

It was found that temperature variations accounted for over 63 percent of the variation in the weekly hot box ratio. The relation between the hot box ratio and average weekly temperature was in the form of a parabola having a minimum value of hot box ratio at 41 F, and increasingly greater values as the temperature difference increased in either direction from 41 F.

When the hot box ratio for the previous week was added as a second independent variable it was possible to explain 75 percent of the total variation. It was thought that the increased correlation obtained by the addition of this second variable may have actually been due to temperature during the previous week. However, when the previous week's temperature was substituted for the previous week's hot box ratio, no significant increase in correlation was noted over that obtained when only one independent variable, the current week's temperature, was used. Lagged temperature, then, was not relevant. The hot box ratio for one week was apparently influenced by a number of other miscellaneous conditions present in the preceding week, as measured by the hot box ratio for that week. However, available data did not permit segregation of the influences reflected in the hot box ratio of the previous week that affected the current week's ratio.

Several other variables, including weekly rainfall, percent of loaded cars, and cars handled per oiler man-day, were tested in attempts to seek other relevant factors influencing the weekly hot box ratio. However, none of these other variables proved important, as statistical tests showed that the slight correlation obtained with these variables was probably due to sampling fluctuations in the data.

(c) Monthly Temperature Variations — The daily data for Division I of Railroad A for 1948 were combined to obtain monthly averages which were subjected to multiple correlation analysis. The relation between the

hot box ratio and average monthly temperature was found to be exactly the same as that found for weekly figures on the same division; but while this same function explained only 63 percent of the variation in the weekly hot box ratio, it explained 75 percent of the variation in the monthly hot box ratio. In other words, the influence of temperature on the hot box ratio increased as the time unit was increased from a week to a month. This was due to the reduction of random variations which resulted from the averaging of weekly into monthly data.

Attempts to incorporate in the analysis such other variables as rainfall, percent of loaded cars, oiler man-days, and cars handled per oiler man-day were unsuccessful. Once temperature had been taken into account, no further relationship could be detected between the unexplained fluctuations in the hot box ratio and the four other variables.

When multiple correlation methods were applied to system records for Railroad A, it was also found that temperature variations were highly relevant to monthly fluctuations in the car miles per set-off. The influence of temperature was more clearly brought out through the use of a monthly temperature index constructed by weighting average daily temperatures according to the amount of their deviations from a specified central range — in this case, 30-60 F. Such an index accounted for 72 percent of the monthly fluctuations in car miles per set-off from 1937-1941 and 49 percent of the variations from 1946-1949. After the effects of temperature had been removed from the monthly car miles per set-off, no further relationship could be detected between this variable and other factors for which data were available.

The relation between monthly temperature and monthly set-off performance is further illustrated in Fig. 9, showing the monthly hot box set-offs per million car miles and the average monthly temperatures on Railroads A and B for 1948. The monthly temperatures for the entire systems were determined by finding the temperature on groups of divisions in the same temperature area and weighting the temperatures for each division group according to the number of car miles run. Figure 9 illustrates the poor set-off performance which generally accompanies extremes of high or low temperatures.

(d) Annual Temperature Variations — In the light of the previous discussions of temperature effects, it is reasonable to assume that variations in annual hot box occurrence may be to some extent explained by variations in the amounts of extreme temperatures experienced from year to year. To investigate the factors influencing annual variations in hot-box occurrence, records were obtained for annual car miles per set-off and several other possibly pertinent variables on Railroad A from 1937 through 1949. It was not possible to obtain data for years prior to

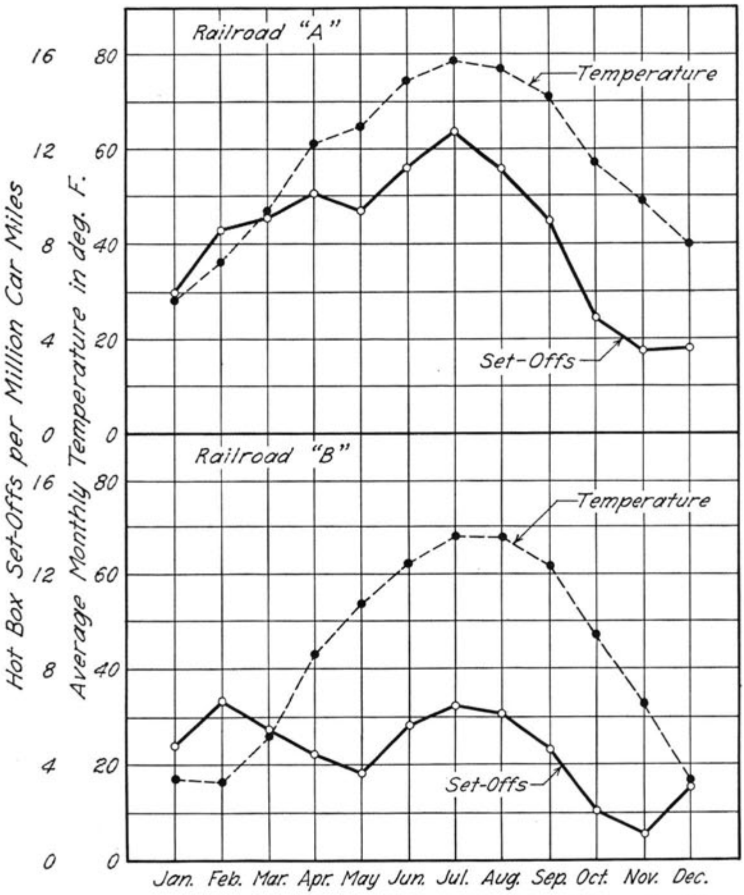

Fig. 9. Relation Between Hot Box Set-Offs Per Million Car Miles and Average Monthly Temperature, Railroads A and B, 1948

1937. Since the hot box relations during the war years may have been affected by special conditions, only nine "normal" observations were available on each variable. With such a small sample, fluctuations due to sampling probably exerted large effects on any relationships that may have existed between the variables. The dependent variable used in the multiple correlation analysis was car miles per set-off. A temperature index was used as an independent variable; it was considered a better measure of variations in temperature extremes than annual average temperature. This index was similar to the one used in monthly temperature and hot box correlations. The only variables which could be determined to have an important influence on the annual car miles per set-off were train speed and the temperature index, the former being the more important of the two. Temperature variations alone accounted for only 10 percent of the variations in the dependent variable. It is possible that other factors actually used in the analysis did influence annual set-off performance, but the statistical evidence provided by the available data was not sufficient to detect any such relationships.

(e) Explanation of Temperature Influences — Discussion of seasonal variations of hot boxes with personnel of Railroads A and B engaged in inspecting and repairing journal bearings indicated a number of possible explanations of the influence which temperature has on the development of hot boxes, the most reasonable of which will be summarized.

The effects of low temperatures on hot box occurrence show close correlation with the increased train resistance commonly known to exist at the same temperatures, indicating that the causes of both phenomena are similar. Car oil becomes very viscous at low temperatures, and when a car is moved after standing for a period of time in low temperature there is a tendency for the packing to stick to the journal and promote large waste grabs. The waste may also move in the journal box to a position where it cannot properly feed oil from the bottom of the journal box to the journal surface. Either situation would cause a hot box.

The effects of summer temperatures on hot box occurrence are evidently not in all cases due to immediate elevation of the running temperature of the bearing, but are in large measure due to corollary effects on the lubricating materials used in the bearing assembly. With higher outside air temperatures, the temperature of the waste pack increases, causing the viscosity of the oil in the waste pack to decrease. The oil then tends to drain to the bottom of the journal box, leaving the top portion of the waste dry and fluffy. This dry condition increases the tendency to develop waste grabs. It is possible that small waste grabs may be thus established under bearings of empty cars which will not cause severe overheating until the car is heavily loaded. This might explain the lack of immediate effects of high temperatures.

24. Rainfall

In the multiple correlation analysis for daily hot box set-offs on Division I of Railroad A in 1948, some influence of rainfall was noted in very warm weather, when 20 percent of the variation in daily set-offs was probably due to fluctuations in rainfall. Rainfall tended to reduce the number of set-offs. This fact substantiated the opinions of some railroad men that rain tends to cool off hot journal boxes and therefore reduces the possibilities of serious overheatings. Rainfall could not be found to have any effect, however, on the number of set-offs during cooler weather. Nor was it found to have any significant influence on the number of hot boxes found in yards, regardless of temperature conditions.

In other multiple correlation analyses using time units longer than one day, no relationship between hot boxes and rainfall was detected.

25. Car Weight

A study of hot box set-offs indicated that car weight has a great influence on hot box occurrence. Information was obtained concerning the lading contained in 1624 cars set off with hot boxes on Divisions 1, 3, 5, and 8 of Railroad A during the months of April, July, October, and December of 1948. Though these cars represent 63 percent of the total cars set off on the entire system during the four-month period and 19.5 percent of the total cars set off on the system during the whole year, they may not present an exactly representative picture. Records of the traffic department indicate that approximately 80 percent of the traffic handled by Railroad A is not of a seasonal nature. The distribution of the four months which were selected for study should further tend to minimize any error due to seasonal variations in traffic. Any error which is present is more probably due to variations between the commodities handled on the divisions included in the study and the commodities making up the total traffic of the railroad. In this respect there was little choice with regard to the divisions to be used for the study, since only five out of the nine divisions on the railroad had information concerning the lading of cars set off. The one division omitted from the study which had information on the lading of the cars had approximately 200 hot boxes set off in the four selected months; addition of these cars to the sample would contribute little to the accuracy of the results.

The traffic department furnished statistics regarding the commodities handled on Railroad A but could not furnish a report covering traffic handled by separate divisions. A report was obtained which showed total traffic broken down into 31 principal commodity groups for the year 1948, from which a division of loaded car miles by commodity could be approximated. The degree of accuracy of this estimate is such that the total of the estimated loaded car miles by commodity is within 1 percent of the total loaded car miles reported to the ICC. Using "Miscellaneous" freight as an example, the method of finding the loaded car miles for each commodity is as follows:

$$\text{"Misc." Freight Loaded Car Miles} = \frac{\text{Net Ton Miles of "Misc." Freight}}{\text{Av. Net Tons per Car for "Misc." Freight}}$$

The 31 commodities listed in the traffic department report have been classified into 6 groups (using net weight of load as a basis of classification) each of which includes all the commodities in a 10-ton range of average loading — i.e., one group for commodities whose average loading is between 10 and 20 tons per car, another group for those whose

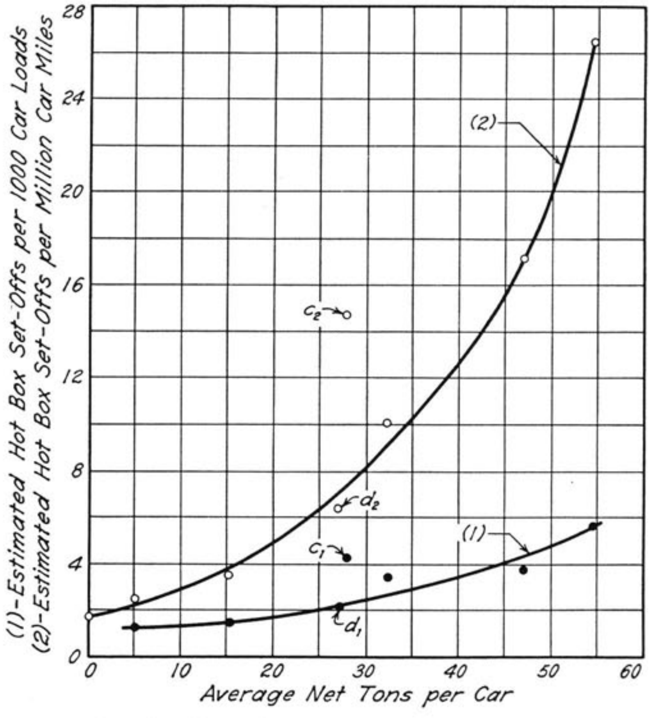

Fig. 10. Relation of Estimated Hot Box Set-Offs and Average Net Tons Per Car on Railroad A, 1948

average loading is between 20 and 30 tons per car and so on. For each group an estimate was made of the loaded car miles and the total hot boxes set off on the assumption that the sample of hot boxes selected produced representative results. In addition, the actual empty car miles were obtained and an estimate was made of the total empty cars set off on account of hot boxes. On the basis of these values Fig. 10 was prepared, which shows the relation in 1948 between estimated hot boxes per million car miles and average loading of the car on Railroad A. It illustrates graphically the large influence of car weight on hot box occurrence.

Figure 10 also shows the set-offs per 1000 car loads for different values of net load in the car. This basis of comparison yields the same trend as a comparison on a car-mile basis.

Though the data used as a basis for Fig. 10 are not exact, the only points which do not follow the general trend are points (c), which represent the group of commodities whose average loading is between 20 and 30 tons. Over 35 percent of the traffic in this group is handled in tank cars, which seem to be notoriously poor with regard to hot box occurrence for some reason other than the weight of the car. If the commodities handled in tank cars are removed from this group and points are plotted representing the data for the rest of the traffic in the group, they then fit in with the trend established by the rest of the weight groups. This is indicated by points (d) on Fig. 10.

Data were obtained regarding the lading of 91.5 percent of the hot box set-offs on Railroad B during 1948. While these data indicated the same general trend — heavier cars had more set-offs — the policy of Railroad B influenced the set-off performance of cars with different weight loads. On manifest trains, which usually contain many lightly loaded cars, the crews were instructed to set off cars with hot boxes immediately, without making any attempt to repair them. On other trains, which usually contain many heavily loaded cars, the crews were instructed to try to carry cars with hot boxes forward into terminals. Hence the comparative set-off performance of light and heavy loads on Railroad B does not accurately indicate the importance of the influence of car weight. Furthermore, it was not possible to obtain traffic statistics which permitted estimation of loaded car miles by commodity groups. For these reasons data obtained on Railroad B have not been presented.

As the weight of a car increases, minor defects present in the bearing assembly become more important. Lightly loaded cars may run satisfactorily with some defects present which would result in overheating if the load in the car were increased.

One large eastern railroad has recognized the importance of car weight in obtaining superior bearing performance by its practice of stenciling a load limit of 25 tons on cars which were designed for use in special high speed merchandise service. Under ordinary circumstances these cars would have had load limits of approximately 62 tons.

26. Length of Haul

A study of the origin points of hot box set-offs on Railroad A gave information concerning the influence of length of haul. On this railroad the origin point of the car designates the beginning of road haul movement for the car and so does not necessarily coincide with the originating point of the shipment. In the cases studied, the originating point was a large classification yard where all cars were run over a hump during switching. In addition, a large proportion of the loaded cars leaving this yard were actually loaded in the immediate terminal area.

For five selected months of 1948 a tabulation was made of the number of cars set off with hot boxes on Division 1 which originated at terminal 1-2 on Railroad A, showing the station at which the car was set off and the distance of the station from the originating point. From these data an average distance of 81.0 miles from origin was obtained, with 64 percent of the cases occurring below average distance. Table 10 shows the distance of these set-offs by 25-mile increments from point of origin. In the corresponding period the average haul per ton was 262 miles and the average per carload approximately 298 miles for the entire railroad.

Table 10

Distance Distribution of Hot Box Set-Offs Originating at One Point: Terminal 1-2, Railroad A, 1948

Group	Distance from Origin, Miles	Hot Boxes Set Off	Percent of Total in Group	Total Miles from Origin for Group	Average Miles from Origin for Group
1	0–25	37	12.2	815	22.0
2	25–50	84	27.7	3020	36.0
3	50–75	62	20.5	3701	59.7
4	75–100	23	7.6	1970	85.6
5	100–125	22	7.3	2386	108.5
6	125–150	34	11.2	4677	137.3
7	150–175	9	3.0	1497	166.3
8	175–200	20	6.6	3620	181.0
9	200–225	4	1.3	868	217.0
10	225–250	3	1.0	702	234.0
11	250–275	4	1.3	1035	258.8
12	275–300	1	0.3	288	288.0
Total	0–300	303	100.0	24,579	81.0

The fact that hot boxes develop in such short distances from the originating point suggests that minor defects may be present in the journal boxes of empty cars which cause overheating after the car is loaded. It also indicates that switching operations may set up conditions in the journal boxes which cause overheating. The main influence of switching operations would be to cause waste grabs, either directly or indirectly. Evidence that switching operations do influence the development of hot boxes is indicated in Table 10. Groups 6 and 8 include set-offs occurring at 25-50 miles distance from two points where some trains were reclassified. While groups 6 and 8 show a rise in the number of set-offs, the rest of groups 3-10 show a steady trend downward.

It is probable that in illustrating the influence of car weight on set-offs per million car miles Fig. 10 has also included in it some of the influences of length of haul. In general, light loads move longer distances than do heavy loads, a condition which alone would tend to cause the set-offs per million car miles for light loads to be less than that for heavy loads.

When the set-offs per 1000 car loads were compared it was also found that as the load increased the number of hot boxes increased. However, the percentage increase in hot boxes for a given increase in loading was not as high as for the car-mile comparison, indicating that the effects of length of haul did influence the latter.

27. Train Speed

High speeds introduce shocks which give high momentary bearing loads and which also jar and roll the packing and thus increase the tendency to develop waste grabs. High speeds also increased the running temperature of the bearing. These facts lead to the conclusion that higher speeds would increase the tendency to develop hot boxes.

It was not possible to conduct any conclusive special studies regarding the bearing performance of trains which operated at different speeds, since variations in speed were usually accompanied by variations in car weight and the amount of lubrication attention given the cars.

In a simple correlation analysis it was found that variations in annual train speed, measured in train miles per train hour, explained a large portion of the variations in annual car miles per set-off on Railroad A. For the 9 peace-time years 1937-1941 and 1946-1949, variations in speed explained 65 percent of the variations in car miles per set-off; for the entire 13-year period 1937-1949 this value was 74 percent. An increase in speed resulted in a decrease in the car miles per set-off.

The results of the simple correlation analysis indicate that the general increase in freight train speed which has taken place since World War II may be one of the main reasons for the general continuous decline in car miles per set-off during the same period.

28. Age of Prior Periodical Repacking Date

At various times there is agitation to reduce the specified period for repacking of journal boxes to alleviate the hot box situation.

To determine the effect of the date of previous periodical repacking of journal boxes on the development of hot boxes, the repack dates of 1212 cars set out of trains because of hot boxes were obtained. These cars were set out on Division I of Railroad A in the period April-December 1948.

The results of this investigation are accompanied in Table 11 by results of two similar studies which were reported to the AAR Mechanical Division in 1939.

Judging by Table 11, all three studies indicate that the date of previous periodical repacking does not affect the development of hot boxes. Actually, however, such a conclusion would be permissible only if the distribution of total cars in service on Division I repacked by the time intervals shown in Table 11 was the same as that of cars set out because of hot boxes. Since no data were obtainable on the total number of cars in service repacked in each time interval, the effect of date of previous repacking on the development of hot boxes remains indeterminate.

29. Daily Inspection and Lubrication Attention

Multiple correlation analyses failed to establish any significant relationship between the development of hot boxes on Railroad A and the oiler working force. This held true regardless of whether weekly, monthly, or annual variations in hot boxes were being investigated. The independent variables used to represent the amount of attention given by oilers were all based in part on the number of oiler man-days.

Table 11
Age of Repack Date on Cars Set Off for Hot Boxes

Age of Prior Periodical Repacking Date, Months	No. of Hot Boxes Set Off in Period			Hot Boxes Set Off in Period as Percent of Total		
	Railroad A 1948	*Studies Reported to AAR—1939*		*Railroad A 1948*	*Studies Reported to AAR—1939*	
		I	*II*		*I*	*II*
0–2	180	149	1086	14.8	8.4	14.6
3–6	308	557	1871	25.4	31.2	25.1
7–10	322	487	1899	26.6	27.4	25.5
11–15	318	465	1764	26.2	26.0	23.7
Over 15	84	125	830	7.0	7.0	11.1
Total	1212	1783	7450	100.0	100.0	100.0

A special study of the comparative performance of two groups of cars receiving different amounts of lubrication attention was made on Railroad A. While this study seemed to indicate that more attention resulted in fewer hot boxes, definite conclusions were not possible because of differences in car weight and train speed for the groups of cars studied.

One reason why it is difficult to determine the effects of variations in lubrication attention on hot-box performance is that it is almost impossible to accurately establish the variations in attention. The only statistics concerning attention which were available for use in the multiple correlation analysis were the oiler man-days, modified by certain ratios to take account of traffic variations.

For various reasons the oiler man-days is probably not an accurate measure of attention variations, one being that for car oilers the ratio of the time actually worked to the total time on duty is low. Even at large classification yards, it was found, train yard oilers were working only about one-half of the time on duty. This does not imply poor management, since delays to trains for lubrication attention would be excessive if fewer men were on duty. Since the ratio of time actually worked to total time on duty is low, it may vary considerably. This ratio may conceivably change from 0.45 to 0.55, with resultant changes in the amount of attention which would not be indicated by the number of oiler man-days.

Another reason why the oiler man-days is not an accurate measure of attention variations is that it does not indicate changes in the effectiveness of the oiling force. The hot-box performance of the railroad will be sensitive to changes in location of the work assignments of a relatively small proportion of the oiler force. Changes of this type alter the effectiveness of the oiler force greatly, but will not necessarily be detectable in reports showing the total oiling force. For these reasons it is doubtful that division records or system records will ever develop a significant correlation between variations in oiler work force and those in hot-box performance.

A conclusive analysis of the economics of variations in attention and resulting variations in hot box performance would require substantial equality of loading and speed of cars studied in order to insure isolation of the effect of attention. Another factor to be considered is the influence of competing modes of transportation on a comparison of this type. Different classes of freight traffic are subject to varying degrees of competition from other modes of transportation; this alone can cause differences in handling costs and transportation charges. Any attempts to compare handling costs of different classes of freight traffic are of dubious economic value. Therefore, in a study of the economics of attention and hot box occurrence the commodities handled in and the revenues received from the cars included in the investigation should be as nearly equal as possible. These requirements indicate that the best method of making such a study would be to investigate the records of one large loading point where attention to the cars originated has varied over a period of time. The effect of temperature variations would have to be taken into account in such a study, but periods of substantially equal temperature could be compared. The effect of variations in attention could thus be fairly well isolated. In measuring variations in attention, it would be important to use variations in actual attention received rather than variations in work assignments.

VII. SUMMARY OF RESULTS AND CONCLUSIONS

Considerable differences were found to exist between the methods used on the two railroads in handling of cars developing hot boxes between terminals. Briefly, no repairs were made to cars with defective bearings by the train crews on Railroad A, whereas on Railroad B considerable work was done by the train crews, both in attempts to prevent setting cars off and in conjunction with picking up cars which had been set off. As a result the number of car miles per hot box set-off was found to be a poor comparative measure of relative hot box troubles between terminals on the two railroads.

In the cases studied, it was estimated that the number of cars repaired for hot boxes was approximately 2.5-4.4 times as great as the number of set-offs. Hence the number of set-offs was also found to be a poor indication of the total number of service failures.

Within a given year, when all hot boxes were considered, both railroads obtained about the same performance. However, in 1951 the failure incidence was much higher than in 1948.

Of the defects on cars which result in interruption of service, hot boxes are the most prevelant. Sample studies of freight train delays due to mechanical failure of car equipment showed that the percentage of delay due to hot boxes was 73.7 on Railroad A and 79.3 on Railroad B.

For comparing costs of operation, use has been made of the cost per 1000 car miles. In the rest of this chapter, wherever comparisons of costs are made, it is to be understood that this unit is being used.

Although the relative number of set-offs was much lower on Railroad B than on Railroad A, more train delay occurred in conjunction with the set-offs on Railroad B, with the result that the costs of set-offs were estimated to be only 7 percent lower on Railroad B. Large amounts of train delay also occurred on Railroad B because of hot boxes on cars other than those set off, which was the main reason why the costs of these hot boxes were 131-142 percent higher on Railroad B than on Railroad A. The total costs of hot boxes, considering both types, were 41-46 percent higher on Railroad B than on Railroad A.

On each railroad the total cost of hot boxes was between 91 and 97 percent higher for 1951 than for 1948, because of the combined influence of large increases in failure incidence and in unit costs on both roads.

Accident costs due to broken and burned-off journals on all Class I railroads were 146 percent higher for 1951 than for 1948.

The portion of determined costs attributable to all service failures, including hot boxes, accidents, and fires, was 20-26 percent for 1948 and 28-34 percent for 1951. Thus, while bearing service failures are matters of great interest and concern, they do not cause the majority of expenses attributable to solid bearings.

The costs of routine inspection and lubrication were found to be very important, constituting 56-68 percent of the total determined costs of solid journal bearing operation. The increase in 1951 costs over 1948 costs for this work was due mainly to increased unit costs. The amount of increase was much higher on Railroad B than on Railroad A because the amount of labor used was greatly reduced on Railroad A when the five-day work week took effect in September 1949, while on Railroad B it remained almost constant.

The total determined costs of solid journal bearing operation per 1000 car miles were estimated to be as follows:

	1948	*1951*	*Increase (1951 vs 1948)*
Railroad A	$5.33	$7.59	42.6%
Railroad B	$5.43	$8.53	57.2%

The individual items and classes of costs entering into these determined costs are shown in Table 8 and Figs. 5 and 6. The total determined costs were higher on Railroad B than on Railroad A by only 2 percent in 1948, but by 12 percent in 1951. The large difference in 1951 costs is largely due to the reduction on Railroad A, in labor assigned to bearing inspection and lubrication. The comparison made in Fig. 6 showed that in 1948, when the total determined costs were almost identical, lower labor costs on Railroad B were being offset by higher train delay costs.

There are other important costs arising from solid journal bearing operation which could not be determined. Among these are the costs of uncertain amounts of fuel consumption, lading damage claims, coupler and draft gear maintenance, winter train tonnage reductions, and personal injuries. These were discussed in Chapter V.

Another important intangible consideration is that present freight car repair and inspection procedures are in a large measure associated with the attention requirements and the service failures of solid journal bearings. Bearing service failures alone contribute to uneconomical practices, but the limitations imposed by requirements of everyday lubrication attention should not be overlooked. Considered together, both of these features of solid journal bearings are major factors in causing slow movement of trains through intermediate terminals and in the necessity for having numerous small car repair points. No estimates have been made of costs of such uneconomical practices, which are in part attributable to solid journal bearing operation.

The studies of factors influencing the development of hot boxes led to the conclusion that the tendency to develop hot boxes was increased by:

1. Atmospheric temperature higher or lower than approximately 40 F. The development of hot boxes was at a minimum when the temperature was 40 F. Extreme cold or hot weather was accompanied by increased numbers of hot boxes. Though cold weather was found to result in increased numbers of hot boxes within a single day, the same relationship could not be established for hot weather.
2. Increasing car weight.
3. Increasing train speed.

There was some indication that rainfall aided in cooling journal boxes and therefore it reduced the development of serious overheatings in very warm weather.

It was discovered that loaded cars develop hot boxes after moving relatively short distances from classification yards or loading points. This suggests that many of the conditions that caused these hot boxes either (1) were brought about by yard switching or (2) were present while the car was running empty but were not serious enough to be a cause of overheating at that time.

No correlation could be established between variations in the oiler working force and the development of hot boxes. This does not imply that there is no relation between the amount of daily attention and the development of hot boxes. It is probable that the available data were too limited to reveal any correlation and that they did not measure significant variations in the amount or effectiveness of the oiler working force.

APPENDIX A: METHODS USED TO DETERMINE NUMBER OF HOT BOXES OF VARIOUS TYPES

30. Calculations

(a) Railroad A—The calculations for determining the number of each type of hot box on Railroad A are based on four principal sources:

1. A railroad report showing the number of freight cars set off between division terminals. This report is made up monthly at each division office and forwarded to the main offices, where a recapitulation is made for the entire system. It was obtained for both **1948** and **1951**.
2. A railroad report showing the total wheels changed for all defects, and total wheels changed because of cut journals. This report is made up monthly at each repair point and forwarded to the main offices. It also was obtained for both **1948** and **1951**.
3. A sample taken of the billing and repair cards of **2922** cars repaired for hot journals at **11** points on three divisions of Railroad A. This sample covered repairs made to cars during **1948**.
4. A study of the final repairs made to **1882** cars set off in **1948** between division terminals on Division I of Railroad A.

The calculations used assume that the results of the latter two samples of repairs applied to **1951** as well as to **1948**, insofar as the relative frequency of various types of repairs is concerned. Detailed calculations are shown for **1948** along with basic information necessary to complete the calculations for **1951**.

(1) Basic Information

A. Number of Hot Box Set-offs

1948	8322
1951	12420

B. Number of Pairs of Wheels Changed Because of Cut Journals

1948	14263
1951	19717

C. Sample of Cars Repaired for Hot Boxes, 1948

Div.	No. Rep. Pts.	Cut Journals		Rebrass	R and R	Total
		Axles	Cars	Cars	Cars	Cars
			I. Road Set-offs			
1	4	(....)	1004	123	164	1291
4	4	(....)	27	7	2	36
8	3	(....)	69	3	3	75
Total	11	(....)	1100	133	169	1402

II. Found in Yard

1	4	(. . . .)	605	345	126	1076
4	4	(. . . .)	130	117	14	261
8	3	(. . . .)	136	47	0	183
Total	11	(. . . .)	871	509	140	1520

III. Total Sample

1	4	1657	1609	468	290	2367
4	4	160	157	124	16	297
8	3	217	205	50	3	258
Total	11	2034	1971	642	309	2922

Note: Calculations for 1951 also used ratios from this sample.

D. Shop Track Repairs to Hot Boxes Set Off on Division I, 1948

I. Set-offs repaired on shop tracks

a. Cut Journals, Cars	1294
b. Rebrasses, Cars	142
c. R and R, Cars	172
d. Total, Cars	1608

II. Set-offs with no record of shop track repairs 274

III. Total Set-offs 1882

Note: Calculations for 1951 also used ratios from this sample.

2) Calculations Using Basic Information, 1948

A. Total Cars with Cut Journals

Sample showed 2034 axles with cut journals on 1971 cars

$$\frac{1971}{2034} \times 14{,}263 = 13{,}821$$

B. Total Axles in Other Positions on Same Cars

$14{,}263 - 13{,}821 = 442$

C. Number of Cut Journals, Rebrasses and R and R's on Set-offs

Sample of 1882 cars set off on Div. I

Cut Journals	1294
Rebrass	142
R and R	172
No record (Road Rebrass)	274
Total	1882

I. Cut Journals

1st axle on cars

$$\frac{1294}{1882} \times 8322 = 5722$$

additional axles, same cars

$$\frac{5722}{13{,}821} \times 442 = 183$$

II. Rebrasses, Cars

$$\frac{142}{1882} \times 8322 = 628$$

III. R and R, Cars

$$\frac{172}{1882} \times 8322 = 761$$

IV. Road Rebrass, Cars

$$\frac{274}{1882} \times 8322 = 1211$$

D. Number of Cut Journals, Rebrasses, R and R's, Other Than Set-offs

Sample of repairs to 1520 cars other than set-offs

Cut Journals	871
Rebrass	509
R and R	140
Total	1520

I. Cut Journals

Number = Total − Those on Set-offs

1st axle on cars

13,821 − 5722 = 8099

additional axles, same cars

442 − 183 = 259

II. Rebrasses, Cars

$$\frac{509}{871} \times 8099 = 4733$$

III. R and R, Cars

$$\frac{140}{871} \times 8099 = 1302$$

(b) Railroad B — The calculations for determining the number of each type of hot box on Railroad B are based on five principal sources:

1. A railroad report showing, by individual cases, the number of freight cars set off with hot boxes between division terminals. This report is made up and summarized in the same manner as the similar report on Railroad A. The complete report, listing individual cases, was obtained for 1948, and a monthly summary listing only totals was obtained for 1951. In addition to serving as a basis for the total set-offs on the railroad for the year, the 1948 report was used as the basis of two other important calculations — temporary repairs to cars set off more than once before final repairs were made, and a study of final repairs made by repair track forces to cars set off on Divisions 6 and 7. This latter study also used records of the car department showing cars sent to repair tracks by individual car number.
2. A railroad report showing the total wheels changed for all defects and total wheels changed due to cut journals. This report is part of a large monthly performance report which is made up at each repair point and forwarded to the main offices. This report was obtained for both 1948 and 1951.
3. A sample taken of the billing and repair cards of 1437 cars repaired for hot journals at 11 points on all nine divisions of Railroad B. This sample covered repairs made to cars during 1948.
4. A study of the type of road repairs made by rip track forces from two repair points (one on Division 1, the other on Division 5) to cars set off with hot boxes during 1948.

5. A study of individual conductor train delay reports for the year **1948**. Figures obtained from the delay reports of Divisions **7**, **8**, and **9** were used to calculate the number and type of preliminary repairs made by train crews before setting off cars with hot boxes. Figures obtained from delay reports of Divisions **1**, **6**, **7**, **8**, and **9** were used to calculate the number and type of all repairs made by train crews to cars developing hot boxes while enroute between division terminals.

The calculations made use of the general assumption that the relative frequency of various types of repairs, as determined by the several special studies made for conditions in **1948**, also applied to **1951**. As for Railroad A, detailed calculations are shown for **1948** along with basic information necessary to complete the calculations for **1951**.

(1) Basic Information

A. Number of Cars Set Off for Hot Boxes

1948	3386
1951	5380

B. Number of Hot Box Set-offs

1948	3505
1951	5569

C. Number of Pairs of Wheels Changed Because of Cut Journals

1948	8029
1951	12633

D. Sample of Cars Repaired for Hot Boxes by Repair Track Forces, 1948 (Includes all final repairs—road repairs to destination and repairs made at repair track. Does not include as separate cases road repairs made by repair track forces and the cars then moved to repair track.)

Div.	No. Rep. Pts.	Cut Journals		Rebrass	R and R	Total
		Axles	Cars	Cars	Cars	Cars
			I. ROAD SET-OFFS			
1	1	(...)	12	3	0	15
2	1	(...)	4	0	0	4
3	2	(...)	12	6	0	18
4	1	(...)	13	0	0	13
5	1	(...)	22	4	2	28
6	2	(...)	90	55	0	145
7	1	(...)	24	6	0	30
8	1	(...)	8	3	0	11
9	1	(...)	8	5	0	13
Total	11	(...)	193	82	2	277
			g	*h*	*j*	
			II. FOUND IN YARD			
1	1	(...)	67	30	0	97
2	1	(...)	67	29	12	108
3	2	(...)	37	117	16	170
4	1	(...)	50	26	0	76
5	1	(...)	43	39	3	85

Div.	No. Rep. Pts.	Cut Journals		Rebrass	R and R	Total
		Axles	Cars	Cars	Cars	Cars
		II. Found in Yard				
6	2	(...)	200	169	10	379
7	1	(...)	54	19	8	81
8	1	(...)	29	109	9	147
9	1	(...)	6	10	1	17
Total	11	(...)	553	548	59	1160
			m	*n*	*p*	
		III. Total Sample				
1	1	88	79	33	0	112
2	1	75	71	29	12	112
3	2	50	49	123	16	188
4	1	69	63	26	0	89
5	1	66	65	43	5	113
6	2	306	290	224	10	524
7	1	79	78	25	8	111
8	1	37	37	112	9	158
9	1	14	14	15	1	30
Total	11	784	746	630	61	1437
		b	*c*	*d*	*e*	

Note: Calculations for 1951 also used ratios from this sample.

E. Sample Information Regarding Road Repairs Made by Repair Track Forces, 1948

I. Samples on Divisions 6 and 7

Road Repairs	95 (*q*)
Road Set-offs Given Final Repairs by Repair Track Forces	619 (*r*)
Road Repairs by Repair Track Forces and Then Cars Moved to Repair Track	17 (*s*)

II. Samples of Road Repairs by Forces from Two Points

Cars with Wheels Changed	96 (*t*)
Total Cars Repaired	159 (*u*)

Note: Calculations for 1951 also used ratios from this sample.

F. Information Concerning Cars Set Off More Than Once (obtained from Set-off Report)

	No. of Cars	No. of Times Set Off	Total Times Set Off Over 1st Time	Total Repaired by *Train Crew*	*Repair Track Forces on Road*
	100	2	100	78	22
	8	3	16	13	3
	1	4	3	2	1
1948 Total	109		119	93	26
1951 Total	173		189	148	41

G. Sample of Preliminary Repairs Made by Train Crews Before Setting Off Cars, 1948 (taken from Delay Sheets of Divisions 7, 8, and 9)

Division	Set-offs	Rebrass	Other Work
7	76	35	11
8	102	20	39
9	86	1	25
Total	264	56	75
	v	*w*	*y*

Note: Calculations for 1951 also used ratios from this sample.

H. Sample of Hot Boxes Other Than Pickups Worked On by Train Crews, 1948 (from Train Delay Reports)

Division	Set-offs	Rebrasses	Other Work	Total
	Number of Delays			
1	98	110	804	1012
6	68	23	117	208
7	115	209	241	565
8	119	76	276	471
9	99	14	81	194
Total	499	432	1519	2450
	a	f	*k*	

Note: Calculations for 1951 also used ratios from this sample.

(2) Calculations Using Basic Information, 1948

A. Total Cars Given Final Repairs by Repair Track Forces

I. Cut Journals

$$\frac{c}{b} \times (1)C = \frac{746}{784} \times 8029 = 7640$$

II. Rebrass

$$\frac{d}{c} \times A(\mathrm{I}) = \frac{630}{746} \times 7640 = 6452$$

III. R and R

$$\frac{e}{c} \times A(\mathrm{I}) = \frac{61}{746} \times 7640 = 625$$

IV. Total

$$A(\mathrm{I} + \mathrm{II} + \mathrm{III}) \qquad 14717$$

B. Total Cars Set Off Given Final Repairs by Repair Track Forces

I. Cut Journals

$$\frac{g}{c} \times A(\mathrm{I}) = \frac{193}{746} \times 7640 = 1976$$

II. Rebrass

$$\frac{h}{d} \times A(\mathrm{II}) = \frac{82}{630} \times 6452 = 840$$

III. R and R

$$\frac{j}{e} \times A(\mathrm{III}) = \frac{2}{61} \times 625 = 20$$

IV. Total

$$B(\mathrm{I} + \mathrm{II} + \mathrm{III}) \qquad 2836$$

C. Total Cars Other Than Set-offs Given Final Repairs by Repair Track Forces

I. Cut Journals

$$A(\mathrm{I}) - B(\mathrm{I}) = 7640 - 1976 = 5664$$

II. Rebrass

$$A(\mathrm{II}) - B(\mathrm{II}) = 6452 - 840 = 5612$$

III. R and R

$$A(\mathrm{III}) - B(\mathrm{III}) = 625 - 20 = 605$$

D. Set-offs Repaired on Road by Repair Track Forces

I. Total Cars

$$\frac{q}{r} \times B(\mathrm{IV}) = \frac{95}{619} \times 2836 = 435$$

II. Cars Moved to Repair Track

$$\frac{s}{q} \times D(\mathrm{I}) = \frac{17}{95} \times 435 = 78$$

III. Cars Rewheeled on Road

$$\frac{t}{u} \times D(\mathrm{I}) = \frac{96}{159} \times 435 = 263$$

IV. Cars Rebrassed

Total $= D(\mathrm{I}) - D(\mathrm{III}) = 435 - 263 = 172$

To Destination $=$ Total $- D(\mathrm{II}) = 172 - 78 = 94$

V. Additional Rebrasses on Cars Set Off More Than Once (Refer to Basic Information, Item F) $= 26$

E. Cars Set Off Repaired at Repair Track

I. Cut Journals

$B(\mathrm{I}) - D(\mathrm{III}) = 1976 - 263 = 1713$

II. Rebrass

$B(\mathrm{II}) - D(\mathrm{IV})$ (To Dest.) $= 840 - 94 = 746$

III. R and R

$B(\mathrm{III}) = 20$

IV. Total

$E(\mathrm{I} + \mathrm{II} + \mathrm{III}) = 2479$

F. Number of Additional Axles with Cut Journals on Same Cars Repaired at Repair Track

I. On Hot Boxes Set Off on Road

$$\text{Total axles} = \frac{b}{c} \times B(\mathrm{I}) = \frac{784}{746} \times 1976 = 2076$$

Additional Axles $=$ Total $- B(\mathrm{I}) = 2076 - 1976 = 100$

II. On Other Hot Boxes

$$\text{Total Axles} = \frac{b}{c} \times C(\mathrm{I}) = \frac{784}{746} \times 5664 = 5953$$

Additional Axles $=$ Total $- C(\mathrm{I}) = 5953 - 5664 = 289$

G. Total Set-offs Worked on by Train Crews

I. Moved to Repair Track

$B(\mathrm{IV}) - D(\mathrm{I}) + 93 = 2836 - 435 + 93 = 2494$

Note: 93 additional Set-offs from Basic Information, Item F.

II. To Destination

(1) $A - B(\mathrm{IV}) = 3386 - 2836 = 550$

III. Total Set-offs Worked by Train Crews

$G(\mathrm{I} + \mathrm{II}) = 3044$

H. Preliminary Repairs Made by Train Crews Before Setting Off Car

I. Number of Rebrasses

$$\frac{w}{v} \times (1)B = \frac{56}{264} \times 3505 = 743$$

II. Other Work

$$\frac{y}{v} \times (1)B = \frac{75}{264} \times 3505 = 996$$

I. Number of Hot Boxes Other Than Pickups Worked on by Train Crews

I. Rebrassed

$$\frac{f}{a} \times (1)B = \frac{432}{499} \times 3505 = 3034$$

II. Other Work

$$\frac{k}{a} \times (1)B = \frac{1519}{499} \times 3505 = 10{,}670$$

J. Total Other Than Set-offs Worked by Train Crews

I. Rebrasses

$I(\mathrm{I}) - H(\mathrm{I}) = 3034 - 743 = 2291$

II. Other Work

$I(\mathrm{II}) - H(\mathrm{II}) = 10670 - 996 = 9674$

K. Set-offs Rebrassed by Train Crew at Time of Pickup

Sample of conductors repair slips on Div. 6, 1948, showed 145 cars rebrassed at pick-up and 127 cars rebrassed but not set off (same ratio used for 1951 calculations).

$$\frac{145}{127} \times J(\mathrm{I}) = \frac{145}{127} \times 2291 = 2616$$

L. Set-off, Other Work by Train Crew at Time of Pickup

$G(\mathrm{III}) - K = 3044 - 2616 = 428$

M. Set-offs to Destination Worked by Train Crews

$G(\mathrm{II})$ Assumed all were rebrassed = 550

N. Set-offs to Repair Track Worked on by Train Crews

Rebrass = $K - M = 2616 - 550 = 2066$

31. Sampling Techniques

Since information concerning road set-offs and various kinds of road repairs was difficult to locate, it was obtained wherever it was available. Therefore, sampling techniques were not applied to data of this type.

On the other hand, there were copious amounts of data available regarding repairs made to cars at repair tracks. Two techniques were developed for sampling these data, each based on one of the two systems of filing records in general use at repair points.

Under one filing system, all repair records were filed according to the last two digits of the car. To illustrate, records of repairs to XYZ railroad car number 145687 would be placed in a file pocket numbered 87, repairs to XYZ 34553 filed under 53 and so on. With this filing system all repair records can be kept in 100 file pockets. Wherever this filing system was in use, the sample of repairs was made by (1) selecting 10 of the 100 file pockets at random and by (2) examining the repair records for these 10 files for an entire year. In this manner, information was obtained concerning approximately 10 percent of the repairs made at the point during the year because of a certain defect.

With the other filing system, repair records were filed according to the date of repairs. Wherever this filing system was in use, the sample of repairs was made by (1) selecting 3 working days of each month of the year at random and (2) examining repair records for these days.

It was found that more representative data were obtained for application to system totals if small samples were taken at many points than if large samples were taken at fewer points. Either of the sampling techniques described should give representative results if the minimum sample size is 60 repair records.

APPENDIX B: DELAYS TO CARS REPAIRED FOR HOT BOXES AND FOR PERIODIC REPACKING OF JOURNAL BOXES

The average days' delay to cars out of service for hot boxes or periodic repacking of journal boxes was computed from three basic sources:

1. Samples of billing and repair cards which showed date repairs were completed. This information was obtained concurrently with the samples of repairs discussed under Appendix A.
2. Repair track or yard office records showing the date when cars were found in need of repairs (bad-order date). These records were also obtained concurrently with the repair samples.
3. The report of hot boxes set off between division terminals, which showed the dates when individual cars were set out of trains.

An important consideration which affects the method used to compute the delays for cars sent to the repair track is the customary procedures used in switching cars on and off the repair track. Ordinarily, cars needing repairs are switched to the repair track before the start of the working day, and cars on which repairs have been completed are removed from the repair track after the end of the working day. Thus, defective cars are usually discovered in bad order sometime prior to 6 a.m. of the day they are switched on the repair track and are not put into trains for forwarding to destination until approximately midnight of the day repairs are completed. The method for assigning the days of delay to individual cars may be best explained by illustrations which follow.

(1) Cars Sent to Repair Track

Bad Order or Set-off Date	Date Repairs Completed	Days' Delay	Explanation
3/11	3/11	1.0	Regarded as delay from early morning to late evening, or approximately midnight to midnight, 24 hours.
3/11	3/12	1.5	Regarded as delay from noon of first date to midnight of date repairs completed.
3/11	3/13	2.5	
3/11	3/14	3.5	

(2) Cars Repaired on Line

Bad Order or Set-off Date	Date Repairs Completed	Days' Delay	Explanation
3/11	3/12	1.0	Regarded as delay from noon of first date to noon of date repairs completed.
3/11	3/13	2.0	
3/11	3/14	3.0	
	etc.		

The average delays to cars repaired for hot boxes during 1948 are shown in Table 12 for Railroad A and in Table 13 for Railroad B. Average car delays because of periodical repacking in 1948 are shown in Table 14. These same average car delays were used for 1951 in the estimates of cost of operation for 1951.

Table 12

Average Delays to Cars With Hot Boxes, Railroad A, 1948

I. *Cars Set Out on Road*

Div.	No. of Repair Points	To Repair Track Cars	To Repair Track Days Delay	To Destination Cars	To Destination Days Delay
1	4	375	1293.5	158	269.0
4	4	36	106.0		
8	3	76	225.0		
Total		487	1624.5	158	269.0
Average Delay, Days			3.34		1.70

II. *Cars Found in Yard*

Div.	No. of Repair Points	Cut Journals Cars	Cut Journals Days Delay	Rebrass and R and R Cars	Rebrass and R and R Days Delay
1	4	188	452.0	189	399.5
4	2	74	127.0		
8	2	105	266.5	28	46.0
Total		367	845.5	217	445.5
Average Delay, Days			2.30		2.05

Table 13

Average Delays to Cars With Hot Boxes, Railroad B, 1948

I. *Cars Set Out on Road*

Div.	To Repair Track Cars	To Repair Track Days Delay	To Destination Cars	To Destination Days Delay
6	362	1393.0	63	145.0
7	97	417.5	27	52.0
8	116	448.0	3	8.0
Total	575	2258.5	93	205.0
Average Delay, Days		3.93		2.20

II. *Cars Found in Yard*

Div.	Repair Points	Cut Journal Cars	Cut Journal Days Delay	Rebrass Cars	Rebrass Days Delay	R and R Cars	R and R Days Delay
1	1	61	232.5	11	81.5		
2	1	65	152.5	29	42.0	12	20.5
3	2	36	105.0	83	153.0	12	25.0
4	1	26	29.0	11	11.0		
5	1	36	43.5	38	45.5	3	3.0
6	1	27	27.0	19	19.0	8	8.0
7	1	54	103.5	18	39.5	8	11.5
8	1	15	31.5	22	54.0	2	5.0
Total		320	724.5	231	445.5	45	73.0
Average Delay, Days			2.26		1.93		1.62

Table 14

Average Delays to Cars for Periodical Repacking, 1948

I. *Railroad A*

(No data obtained, assumed delay approximately the same as for cars found in yard rebrassed and R and R, since the type of work done and the bad ordering procedure are similar. This average delay was 2.05 days.)

II. *Railroad B*

Div.	Repair Points	Cars	Days Delay
5	1	18	34.5
8	1	47	84.5
Total		65	119.0
Average Delay, Days			1.83

APPENDIX C: DELAYS TO TRAINS DUE TO HOT BOXES AND OTHER MECHANICAL FAILURES OF FREIGHT CARS

Information concerning delays to trains resulting from mechanical failures of freight cars, and in particular from hot boxes, was obtained on both Railroad A and Railroad B for 1948. On Railroad A the source of information was the mechanical failure report, which was a part of the daily situation report and contained the following information regarding mechanical failures of cars:

1. Point of delay
2. Time of delay
3. Defect causing delay
4. Initial, number, and lading of defective car

On Railroad B no such report was available, and for this reason conductors reports of delays to individual trains were used. These reports lacked uniformity in the information given concerning individual delays; many gave only the first three items listed above. This incompleteness was particularly undesirable because the freight crews on Railroad B did considerable work repairing cars on the line, and the lack of explicit information made it impossible, unless stated, to determine whether cars were (1) repaired, (2) set out, (3) picked up, or (4) repaired and picked up. In determining average delays due to different types of situations, therefore, it was necessary to use only those cases in which exact information was given concerning the delay.

In obtaining information, periods from all seasons of the year were included in the sample in as equal a balance as could be maintained in view of the availability of the sources of information used. This was done to insure that the data would be representative of average annual conditions. The data are useful in (1) determining the average delay resulting from various types of hot boxes and (2) demonstrating the fact that hot boxes constitute the major cause of delay resulting from mechanical failure of cars. Selected portions of the data are presented in Table 15 in order to serve the former purpose, and the entire data are shown in Table 16 for the latter purpose. The data shown for 1948 in Table 15 were also used in cost estimates for 1951.

Table 15

Average Delays to Trains Due to Various Types of Hot Boxes, 1948

Div.	Set-Offs No. of Delays	Set-Offs Min. Delay	Rebrasses No. of Delays	Rebrasses Min. Delay	Other Work No. of Delays	Other Work Min. Delay	Pickup No. of Delays	Pickup Min. Delay
I. *Railroad A*								
1	563	16,350					No data	
3	182	3,896						
4	208	7,028						
5	372	11,255						
8	224	4,740						
Total	1549	43,269						
Average Delay, Min.		28.0						
Delay Used in Costs, Min.		28.0					14.0	
II. *Railroad B*								
1	98	2575	110	3500	804	19,185	16	420
6	68	2495	23	965	117	3,465		
7	115	3808	209	7405	241	6,465		
8	119	3115	76	2490	276	6,700	5	110
9	99	1965	14	540	81	1,436	4	45
Total	499	13,958	432	14,900	1519	37,251	25	575
Average Delay, Min.		28.0		34.5		24.5		23.0
Delay Used in Costs, Min.		28.0		35.0		25.0		23.0

(Pickup and Rebrass—23.0 plus 35.0 minus 10.0, or 48.0 min.)
(Pickup and other work—23.0 plus 25.0 minus 10.0 or 38.0 min.)

Table 16

Delays to Trains Due to Hot Boxes and Other Mechanical Failures of Cars, 1948

Cause of Delay	Sampled Delays in Min. for Each Division Number					Total, All Div. Delay Min.	% Total
I. *Railroad A*	1	3	4	5	8		
Hot Boxes	17,040	4,016	8,988	11,445	4,970	46,459	73.72
Other Delay	2,120	2,422	5,978	2,755	3,290	16,565	26.28
Total	19,160	6,438	14,966	14,200	8,260	63,024	100.00

(Other delay was not obtained broken down, but it was mainly due to brake defects.)

II. *Railroad B*	1	4	5	6	7	8	9	Total, All Div. Delay Min.	% Total
Hot Boxes	26,915	9865	9220	7505	18,950	13,210	4,675	90,340	79.28
Bro. Knuckle	2,080	305	150	1065	1,145	525	555	5,825	5.11
Bro. Drawbar	1,375	560	100	740	980	1,185	120	5,060	4.44
Def. Brake Rigg	1,945	850	505	1490	1,135	295	485	6,705	5.88
Bro. Train Line	160	65	140	160	430	160	245	1,360	1.19
Burst Air Hose	155	25		190	185	350	95	1,000	0.88
Brake Sticking	585	120	135	520	355	95	280	2,090	1.84
Misc. Air Def.	35			60	215		65	375	0.33
Shifted Load	95	40		240	105	180	170	830	0.73
Bro. Wheel				370				370	0.32
Total	33,345	11,830	10,250	12,340	23,500	16,000	6,690	113,955	100.00

APPENDIX D: DEVELOPMENT OF TRAIN HOUR VALUES

Delays due to freight car hot boxes are the major cause of train delay attributable to the mechanical failure of car equipment. These delays to trains represent a large economic loss to railroads which have invested heavily in signal systems, roadbeds, and high-capacity locomotives for the primary purpose of expediting train movement. However, evaluation of the costs of train delays is most difficult. In the past the cost of train stops has been evaluated by means of the "Cost of Stopping Trains" formulas, developed for the steam locomotive, which appear in the Proceedings of the AAR Signal Section. A more recent method of determining the cost of delaying a train is through use of the "Freight Train Hour Value" outlined in the 1946 Proceedings of the AAR Signal Section. It should be pointed out that the "Train Hour Value" as such does not include costs of delays to cars in the trains. The statistics used to compute the train hour values were obtained from the *Preliminary Abstract of Railway Statistics,* issued annually by the Bureau of Transport Economics and Statistics, Interstate Commerce Commission.

32. Freight Train Hour Value

This value is based on the amount of ICC operating expense accounts 308, 311, and 392-402 which are assigned and apportioned to road freight service, and in addition the amount of ICC account 331 (locomotive depreciation) which may be assigned and apportioned to road freight service. Payroll taxes at the appropriate rate are added for the amount of labor included in ICC accounts 308, 311, 392, 393, 400, and 401. The cost of these expenses per road freight train hour is outlined in Table 17 for Class I Line-Haul Steam Railroads for the years 1948 and 1950. Two values are shown for each year, one omitting the crew expenses and the other including these expenses (Accounts 392, 393, and 401, and the payroll taxes for these accounts). The use of each of these two values is explained in Appendix F.

The cost of lubrication of freight cars has been included elsewhere in this study, and since this represents approximately 40 percent of the charges made to ICC Account 402, the train hour value less 40 percent of the hourly value of Account 402 is used to evaluate delays to freight trains. Because the statistics necessary to compute the train hour value for 1951 are not yet available, the 1950 value has been used to evaluate delays occurring during 1951. Calculations involved in determining the freight train hour value are also shown.

(1) Calculation of Road Freight Locomotive Depreciation for 1948 (Only Total Locomotive Depreciation was available in the statistics given for 1948, and Road Locomotive Depreciation had to be computed. The actual statistics were given for 1950.)

$$\text{Steam Road Loco. Depreciation} = \frac{\text{Steam Road Loco. Repairs}}{\text{Total Steam Loco. Repairs}} \times \text{Total Steam Loco. Depreciation}$$

$$= \frac{\$336{,}005{,}907}{\$411{,}021{,}206} \times \$39{,}557{,}911$$

$$= \$\ 32{,}338{,}214$$

$$\text{Other Road Loco. Depreciation} = \frac{\text{Other Road Loco. Repairs}}{\text{Total Other Loco. Repairs}} \times \text{Total Other Loco. Depreciation}$$

$$= \frac{\$40{,}776{,}390}{\$59{,}440{,}215} \times \$18{,}904{,}925$$

$$= \$12{,}968{,}907$$

(2) Calculation of Payroll Taxes

	1948	*1950*
Payroll Tax Rate, Percent	5.75	6.00

Accounts No.	Assumed % Labor, Cost of Accts.*	Payroll Tax % of Cost of Accts.		Cost of Accounts		Cost of Payroll Tax	
		1948	*1950*	*1948*	*1950*	*1948*	*1950*
308, 311	70.0	4.0250	4.2000	$376,782,297	$333,086,361	$15,165,487	$13,989,627
400	85.0	4.8875	5.1000	92,676,291	86,485,728	4,529,554	4,410,772
392, 393 and 401	100.0	5.7500	6.0000	564,617,101	525,390,106	32,465,483	31,523,406

(3) Calculation of Costs per Freight Train Hour (Sample Calculation)

$$\text{Cost of Train Fuel (Acct. 394) per Hr.} = \frac{\text{Total Road Frt. Trn. Miles} \times \text{Cost of Acct. 394}}{\text{Ord. Road Frt. Trn. Mi.} \times \text{Total Road Frt. Trn. Hrs.}}$$

$$\text{Using 1948 values:} \quad = \frac{584{,}671{,}346 \times \$492{,}048{,}391}{576{,}750{,}969 \times 36{,}148{,}118}$$

$$= \$13.799$$

* Procedure same as that used by *AAR Signal Section*.

33. Passenger Train Hour Value

This value is based on the amount of ICC operating expense accounts 308, 311, and 392-403 which are assigned and apportioned to road passenger service, and in addition the amount of ICC account 331 (locomotive and passenger car depreciation) which may be assigned and apportioned to road passenger service. Payroll taxes at the appropriate rate are added for the amount of labor included in ICC accounts 308, 311, 392, 393, 400, and 401. The cost of these expenses per road passenger train hour is outlined in Table 18 for Class I Line-Haul Steam Railroads for the years 1948 and 1950. These passenger train hour values were derived by following a procedure similar to that used by the AAR Signal Section in establishing freight train hour values. The passenger train hour

Table 17

Freight Train Hour Value on All Class I Line-Haul Steam Railways

ICC Acc't No.	Description of Account	Costs Assigned and Apportioned to Freight Service 1948	1950	Cost per Freight Train Hour 1948	1950
308	Repairs to Steam Locomotives—Other	$336,005,907	$244,201,871	$9.423	$8.097
311	Repairs to Other Locomotives—Other	40,776,390	88,884,490	1.144	2.947
331	Road Frt. Loco.—Depreciation Steam	32,338,214	28,140,657	0.907	0.933
	Other	12,968,907	35,705,374	0.364	1.184
394	Train Fuel	492,048,391	360,553,815	13.799	11.954
395	Train Power Produced	2,155,550	1,366,865	0.060	0.045
396	Train Power Purchased	6,353,785	6,168,294	0.178	0.205
397	Water for Train Locomotives	22,156,280	17,994,114	0.621	0.597
398	Lubricants for Train Locomotives	14,335,117	13,205,470	0.402	0.438
399	Other Supplies for Train Loco.	6,241,864	5,746,279	0.175	0.190
400	Engine House Expenses—Train	92,676,291	86,485,728	2.599	2.867
402	Train Supplies and Expenses	111,171,966	113,515,232	3.118	3.764
	Payroll Taxes for 308, 311, and 400	19,695,041	18,400,399	0.552	0.610
	Total (No Crew Expenses)	$1,188,923,703	$1,020,368,588	$33.342	$33.831
	Total, Less 40% of Account 402	1,144,454,917	974,962,495	32.095	32.325
392	Train Enginemen	219,254,333	153,793,852	6.149	5.099
393	Train Motormen	39,537,191	83,630,374	1.109	2.773
401	Trainmen	305,825,577	287,965,880	8.576	9.548
	Payroll Taxes for 392, 393, and 401	32,465,483	31,523,406	0.910	1.045
	Total (With Crew Expenses)	$1,786,006,287	$1,577,282,100	$50.086	$52.296
	Total, Less 40% of Account 402	1,741,537,501	1,531,876,001	48.839	50.790
	A. Road Frt. Train Miles, Ordinary	576,750,969	507,907,754		
	B. Road Frt. Train Miles, Total	584,671,346	514,970,639		
	C. Road Frt. Train Hours, Total	36,148,118	30,580,499		
	Train Miles per Train Hour	16.174	16.840		

Table 18

Passenger Train Hour Value on All Class I Line-Haul Steam Railways

ICC Acc't No.	Description of Account	Costs Assigned and Apportioned to Passenger Service 1948	1950	Cost per Passenger Train Hour 1948	1950
308	Repairs to Steam Locomotives—Other	$105,384,973	$ 72,198,470	$9.503	$7.562
311	Repairs to Other Locomotives—Other	48,884,085	73,825,899	4.408	7.732
331	Road Pass. Loco. Depreciation—Steam	10,132,985	7,884,688	0.914	0.826
	Other	11,315,845	17,948,998	1.020	1.880
331	Passenger Train Car Depreciation	27,802,694	29,222,664	2.507	3.061
392	Train Enginemen	63,658,952	42,812,198	5.741	4.484
393	Train Motormen	43,277,909	58,635,762	3.903	6.141
394	Train Fuel	151,784,653	111,809,605	13.687	11.710
395	Train Power Produced	1,995,346	1,814,288	0.180	0.190
396	Train Power Purchased	14,414,712	13,273,413	1.300	1.390
397	Water for Train Locomotives	5,897,249	4,104,844	0.532	0.430
398	Lubricants for Train Locomotives	6,971,040	6,000,895	0.629	0.628
399	Other Supplies for Train Locomotives	2,625,148	2,333,112	0.237	0.244
400	Engine House Expenses—Train	37,044,883	33,079,205	3.341	3.465
401	Trainmen	133,948,469	129,611,835	12.079	13.575
402	Train Supplies and Expenses	97,742,733	98,845,067	8.814	10.352
403	Operating Sleeping Cars	680,564	691,870	0.061	0.072
	Payroll Taxes	21,870,805	21,683,650	1.972	2.271
	Total	$785,433,045	$725,776,463	$70.828	$76.013
	A. Passenger Train Miles	407,132,768	357,545,213		
	B. Passenger Train Hours	11,089,298	9,548,039		
	Train Miles per Train Hour	36.714	37.447		

values have been used to evaluate passenger train delays due to accidents caused by broken or burned-off journals on freight cars. The statistics necessary to compute the train hour value for 1951 were not available at the time of this writing; therefore the 1950 value has been used to evaluate delays occurring during 1951. The calculations involved in determining the passenger train hour value are also shown.

(1) Calculation of Road Passenger Locomotive Depreciation for 1948 (Form similar to that for Calculation 1 under Freight Train Hour Value)

$$\text{Steam Road Locomotive Depreciation} = \frac{\$105{,}384{,}973}{\$109{,}351{,}044} \times \$10{,}514{,}331$$
$$= \$\ 10{,}132{,}985$$

$$\text{Other Road Locomotive Depreciation} = \frac{\$\ 48{,}884{,}085}{\$\ 51{,}337{,}158} \times \$11{,}883{,}690$$
$$= \$\ 11{,}315{,}845$$

(2) Calculation of Payroll Taxes (Form similar to Calculation 2 under Freight Train Hour Value)

Account No.	Cost of Accounts		Cost of Payroll Tax	
	1948	*1950*	*1948*	*1950*
308, 311	$154,269,058	$146,024,369	$ 6,209,330	$ 6,133,023
400	37,044,883	33,079,205	1,810,569	1,687,039
392, 393, 401	240,885,330	231,059,795	13,850,906	13,863,588
	Total Payroll Taxes		$21,870,805	$21,683,650

(3) Calculation of Costs per Passenger Train Hour (Sample Calculation)

$$\text{Cost of Train Fuel (Acct. 394) per hour} = \frac{\text{Cost of Account 394}}{\text{Passenger Train Hours}}$$

Using 1948 values:

$$= \frac{\$151{,}784{,}653}{11{,}089{,}298}$$
$$= \$13.687$$

APPENDIX E: DEVELOPMENT OF CAR DAY VALUES

Losses other than repair and maintenance costs from freight cars inactivated because of mechanical failures are incurred by a railroad in two distinct ways:

1. The cost of owning additional cars in order to have sufficient number on hand to offset those set out because of mechanical failure.
2. The loss of whatever revenue might have been earned by the cars having mechanical failures.

The first item may be considered a revenue loss in the sense of its being a negative cost: if mechanical failures did not occur the railroads would incur so much less expense. If car days lost because of hot boxes are known, it would be possible to estimate the additional cars needed because of this source of car failures, or the fewer number of cars that would be required if this source of car failure were eliminated. It would then be possible to estimate the total investment represented by such additional equipment, and the annual costs associated with it. The annual cost of ownership of this additional supply of equipment would include interest on the investment in the cars, cost of repairs exclusive of those resulting from hot boxes, depreciation, and taxes in so far as the taxes may be affected by the number of cars owned or affected by the investment therein.

Since the per diem rate paid by one railroad for the use of equipment owned by other railroads is supposed to be based on the cost of car ownership, this figure could be applied to the active car days lost by reason of hot boxes to give an approximation of the cost to the railroads that results from the first item above. The use of this method is based on the assumption that an additional number of cars is now required over the number that would be required if hot boxes were eliminated. In 1951, the per diem rate was $1.75. In view of the carriers' contentions in 1949 (274 ICC 383) that the costs of car ownership exceeded this amount, and the further fact that material and labor costs have risen since then, it is quite likely that $1.75 is too low, and that $2.00 would not be overstating the cost of car ownership.

The estimation of the second item has thus far proved even more difficult. If no car shortage exists at the time and place where a mechanical failure occurs, there is obviously no loss of revenue, inasmuch as that car, or another of the same type, would have remained idle anyway. The same is true if a car shortage does exist but the unavailability of cars due to mechanical failures simply postpones the transportation of a commodity by rail. It is only when the unavailability of the car leads to permanent curtailment of rail shipments, whether because of reduced output or because of the use of some other means of transportation, that revenue loss attributable to mechanical failure results. The problem of estimating the revenue loss due to mechanical failures is therefore essentially one of finding some method of distinguishing these various situations from one another, of determining the number of cars having mechanical failures in the situations where rail shipments are permanently curtailed, and of estimating the revenue these cars would have produced had these mechanical failures not occurred.

34. The Method

Since a variety of concepts are involved in the exposition below, the following notation is used for the sake of brevity:

C_d = Car shortage on railroad network(s)
C_s = Car surplus on railroad network(s)
N_r = Number of cars having mechanical failures that would otherwise have earned revenue for the railroad(s)
N_s = Number of cars having mechanical failures that would have remained idle
N_t = Total number of cars having mechanical failures = $N_r + N_s$
R = Revenue per freight car day for serviceable cars
L = Average loss to railroads per car day because of mechanical failures
S = Cost of car ownership per day

The quantity sought is L, the average loss to railroads per car day because of mechanical failures. This quantity is

$$L = \frac{RN_r + SN_s}{N_t} \tag{3}$$

The term SN_s expresses the costs the railroad would save per day on those cars that have mechanical failures and that would not have earned any revenue anyway. In the absence of mechanical failures, these cars would not be needed at all; SN_s therefore represents the saving — i.e., the deduction from costs — that would then result.

The term RN_r represents the extra revenue the railroad would have received per day if these cars had not had mechanical failures.

Dividing the sum of these two terms by the total number of cars having mechanical failures yields L.

The problem, then, becomes one of determining N_r or N_s, since the other three variables on the right-hand side of Eq. (3), namely S,R, and N_t, are presumably given. (For S, the value given is $2 per car day.)

How many freight cars laid up because of mechanical failures would have produced revenue for the railroad had they been in serviceable condition? An answer would seem to lie in a comparison of the car surplus and car shortage figures compiled by the American Railway Car Institute. Both these figures are generally positive at any given time because a surplus of cars of some types at some points does not preclude the existence of shortages of those types of cars at other points or of other types of cars at the same points. Therefore, comparison of these two statistics for any given period indicates the relative degree to which cars are in short supply. Now, if the distribution by terminals of cars having mechanical failures is proportional to the distribution by terminals of shortages and surpluses on the railroad, then the proportion of the cars having mechanical failures that might have earned revenue would be roughly the same as the proportion that the car shortage figure constitutes of the total of car shortages and car surplus, — that is $C_d/(C_d + C_s)$. Making this assumption provides the value of N_r, for then:

$$N_r = \frac{C_d}{C_d + C_s} N_t \tag{4}$$

This also gives the value of N_s, for by definition:

$$N_s = N_t - N_r \tag{5}$$

Substituting Eqs. (4) and (5) in (3) yields:

$$L = \frac{R \dfrac{C_d}{C_d + C_s} N_t + S\left(N_t - \dfrac{C_d}{C_d + C_s} N_t\right)}{N_t}$$

Simplifying and combining terms leads to the following operational formula for estimating L:

$$L = (R - S)\frac{C_d}{C_d + C_s} + S \tag{6}$$

This formula makes automatic adjustment for the effects of car shortages and surpluses on the loss to railroads per car day because of mechanical failure. This follows from the incorporation in it of data on car shortage and surplus. The formula will vary between R and S inclusive. If enough cars are on hand to meet all needs, C_d is zero, the first term on the right of Eq. (6) is also zero, and L reduces to S, the cost of car ownership. If, on the other hand, widespread shortages of cars exist, $C_d/(C_d + C_s)$ is approximately unity, and L becomes equal to $(R-S) + S$, or R. The degree to which L approaches its upper limit, R, depends on the extent of the car shortage during the particular period on the railroad(s) studied.

Incorporating in the per diem rate this method of evaluating revenue loss because of mechanical failure might promote greater efficiency in the use of freight cars and increase the available supply at the very times when this is needed most — in periods of car shortages. The reason is the automatic increase in the value of L as car shortages increase, which would serve to raise the per diem rate and hence provide an added stimulus to efficient use of the cars.

35. Application

Four quantities are involved in the determination of L — car shortage (C_d), car surplus (C_s), revenue per freight car day (R), and the cost of car ownership per day (S). The value of S is presumably fixed. The values of the other three quantities, however, may vary widely not only by period studied and by railroad but also by the type of car. For this reason it would be desirable to apply the formula to each type of car separately wherever possible. Weighting the resulting estimates of L by the relative number of cars of each type having mechanical failures would then yield the over-all value of L for the system for that period.

In the absence of the necessary data by type of car, the formula would have to be applied on a system basis. Offhand, the bias arising from this approximation procedure would seem to be fairly small, though only an actual series of tests can yield a conclusive answer.

The application of the formula to all Class I railroads for 1948 and for 1951 is shown below. The data represent all types of cars since not enough information was available to permit application of the formula to each type of car separately.

For 1951. The car shortage in 1951 amounted to 188,980 and the car surplus to 99,269. The average revenue per freight car day (R) for serviceable cars is obtainable as the total freight revenue for Class I railroads (excluding switching and terminal companies) divided by the product of the number of serviceable home and foreign cars on the line and the number of days in the year. A reasonable value for the cost of car ownership (S) in 1951 would seem to be \$2.00 per car day in view of the fact that the per diem rate had been raised to \$1.75 in 1949 and that prices in 1951 were considerably higher than in 1949.

$$R = \frac{\$8,634,162,673}{1,859,541 \times 365}$$
$$= \$12.72$$

Substituting in Eq. (6):

$$L = (\$12.72 - \$2.00)\left(\frac{188{,}980}{188{,}980 + 99{,}269}\right) + \$2.00$$
$$= \$9.03$$

For 1948. The car shortage was 144,502, the car surplus 232,689, and the average revenue per freight car day for serviceable cars \$11.30. Because prices were somewhat lower that year, S is taken as \$1.75. Substituting these values in Eq. (6):

$$L = (\$11.30 - \$1.75)\left(\frac{144{,}502}{144{,}502 + 232{,}689}\right) + \$1.75$$
$$= \$5.41$$

The total loss to the railroads due to mechanical failures in each of those years would then be the appropriate value of L multiplied by the number of car days lost because of mechanical failure. Maintenance and repair costs are, of course, separate.

These values for L refer to gross loss in revenue, inasmuch as the values of R used above are based on *gross* revenues. Net figures for L could be obtained by converting R to a net basis.

A general picture of the average revenue loss per car day yielded by this method under various car shortage and surplus conditions is provided by Fig. 11. Each line in that figure corresponds to a different figure for revenue per freight car day for serviceable cars, ranging from \$5.00 to \$15.00. The cost of car ownership, S, is assumed to be \$2.00 per car day. The shortage ratio, $\frac{C_d}{C_d + C_s}$ is plotted on the horizontal axis and the revenue loss per car day on the vertical axis. The revenue loss under any car shortage condition and for a particular revenue per freight car day is obtained by entering the computed value of the car shortage ratio on the horizontal axis and reading upward to the line corresponding to that revenue per freight car day and then over to the vertical axis, which yields the desired quantity. The arrows on Fig. 11 illustrate the estimation of L for a period when the car shortage ratio is 30 percent and the revenue per freight car day is \$9.00.

Some allowance would also seem necessary for seasonal variations in number of mechanical failures, in car shortage and surplus, and in revenue per freight car day. This allowance could be made by computing L for each month (or week) separately and deriving the average revenue loss per freight car day for the year by weighting the individual L's by the number of mechanical failures in each period. In the one case where this method was applied, however, it yielded a result practically identical with that obtained by applying the method to the year as a whole. As a general rule, allowance for seasonal variation will significantly affect the final result only when the seasonal patterns of car shortages, mechanical failures, and revenue per freight car day coincide.

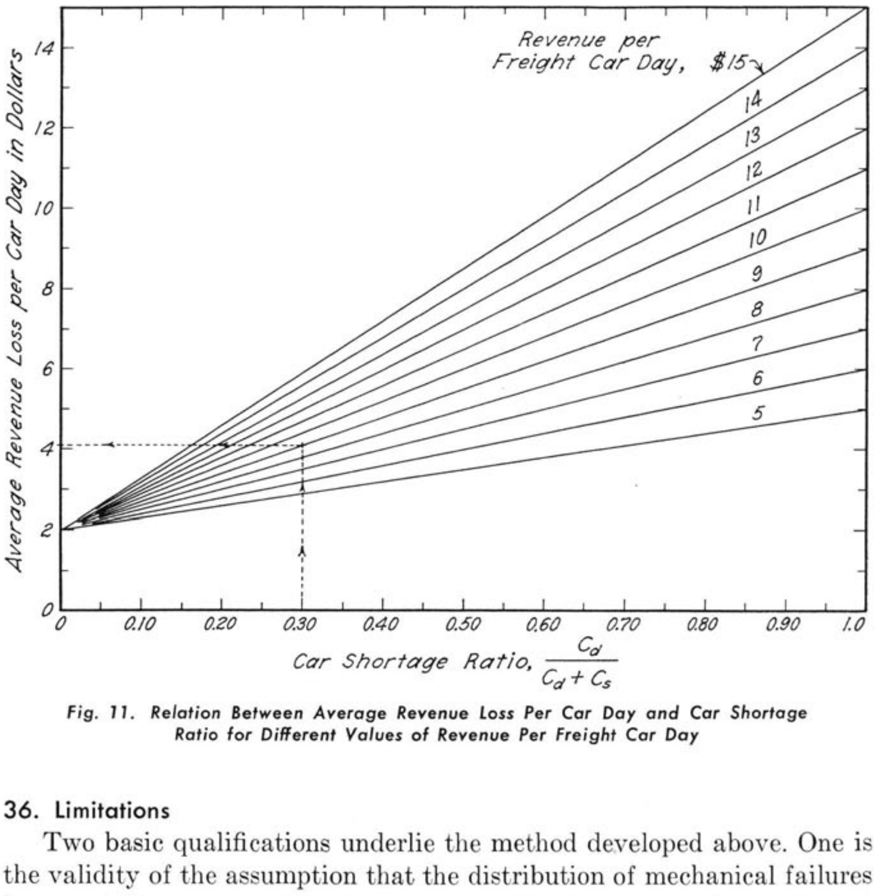

Fig. 11. Relation Between Average Revenue Loss Per Car Day and Car Shortage Ratio for Different Values of Revenue Per Freight Car Day

36. Limitations

Two basic qualifications underlie the method developed above. One is the validity of the assumption that the distribution of mechanical failures by terminals is proportional to the distribution of car shortages and surpluses. This is the kind of assumption that seems reasonable offhand. There is a possibility that there are more mechanical failures at terminals where car surpluses exist, if most of the railroad's cars are at these points. On the other hand, there is the likelihood that cars at terminals where shortages exist may be handled much more quickly (and more roughly), so that the frequency of mechanical failures at these points may tend to increase. At present the relative importance of these two opposite factors cannot be judged; in the absence of evidence to the contrary, it is assumed they would more or less offset each other.

The second qualification arises from the possibility that the goods whose transportation is postponed because of the car shortages are simply transported at a later date with no loss in revenue to the railroad. To some extent this is true. Certain goods may be stored at the siding or in the plant awaiting shipments. Others, however, may be shipped by truck, and the production of still other goods, not easily transported by truck, may simply be curtailed — as is especially true of products of mines, which constitute most of railroad freight revenue tonnage and which, because of their bulk, are not easily stored.

At the same time, two extenuating factors exist that would seem to more than offset the effect on the method of temporary postponement of shipments. One arises from the fact that many of the postponed shipments are never reported in the car shortage figures. When the yard official can induce shippers to set back their schedules without severe complaint, the cars that would otherwise have been needed may not be reported as shortages.

The second is the loss of goodwill by the railroads resulting from the existence of such shortages. No immediate loss in revenue may result from a car shortage, but the periodic occurrence of such shortages is bound to influence a shipper to investigate other means of transportation where possible. The effect of this factor has been highlighted by the increasing share of grain shipments being moved by truck. One reason cited by the grain shippers for this shift is the inability of railroads to supply enough cars.

The absence of mechanical failures might not have eliminated this problem altogether, but it undoubtedly would have helped alleviate car shortages in many instances. The alleviation of even one shortage can save the railroads considerable future revenues. Thus, the shift to trucks for grain shipments first gained momentum in the 1946 harvest when the acute shortage of boxcars led numerous shippers to use trucks. Once begun, the use of trucks continued even after the car shortage had ended.

The effect of this second qualification on the validity of the formula is therefore hard to judge. On the one hand, is the fact that an unknown proportion of the goods whose transportation is postponed by a car shortage does not represent an immediate loss of railroad revenues. For this reason the value for L yielded by the formula is an overestimate. On the other hand, the understatement of car shortage figures and the tendency of shippers to turn permanently to other means of transportation because of the very existence of an occasional severe shortage tends to bias downward the value of L. Although none of these factors is measurable, the cumulative effect of the latter over a long period of time is undoubtedly considerable and is likely to be of sufficient magnitude alone to offset at least the instances where the railroad does not lose revenue because of car shortages. Therefore, it is believed that the net effect of the qualifications accompanying this method is to yield estimates of the loss of revenue to the railroads arising from mechanical failure that are, if anything, on the conservative side.

APPENDIX F: UNIT COSTS OF ITEMS IN COSTS OF HOT BOXES

37. Train Delay Costs

The unit costs of train delays shown in Table 19 are based on the average delays to the train (Appendix C, Table 15) and on the train hour value (Appendix D, Table 17). On Railroad A no repair work on hot boxes was done by train crews; on Railroad B a considerable amount was done. Overtime payments to train crews on Railroad A were a much smaller portion of total crew costs than on Railroad B. In particular, the type of trains on Railroad B on which the crews did most of the work on hot boxes were the trains which also had overtime crew costs most frequently. For these reasons the train hour value with the cost of train crews omitted has been used to evaluate delays on Railroad A, while the train hour value with the cost of train crews included has been used for Railroad B.

Table 19

Unit Costs of Train Delays

Class of Delay	Ave. Train Delay		Train Hour Value		Unit Cost of Delay	
	Min.	Hours	*1948*	*1951*	*1948*	*1951*
I. *Railroad A*						
Set-off and Pickup	42	0.700	$32.095	$32.325	$22.467	$22.628
II. *Railroad B*						
Set-off and Pickup	51	0.850	$48.839	$50.790	$41.513	$43.171
Set-off, Pickup, and Rebrass	76	1.267	48.839	50.790	61.879	64.351
Set-off, Pickup, and Other Work	66	1.100	48.839	50.790	53.723	55.869
Rebrass	35	0.583	48.839	50.790	28.473	29.611
Other Work	25	0.417	$48.839	$50.790	$20.366	$21.179

38. Costs of Delays to Cars in the Train Delayed by the Hot Box

The unit costs of delays to cars in the train delayed by the hot box (Table 20) are based on the average delays to the train (Appendix C, Table 15), the average number of cars in the train, and the car day value (Appendix E). The latter two items were:

	1948	*1951*
Car Day Value	$5.41	$9.03
Ave. No. Cars in Train, Railroad A	56.88	55.89
Railroad B	60.30	59.94

The basic calculations used to determine these car delay costs were:

$$\text{Ave. Car Days Delay} = \frac{\text{Average Delay Hrs.}}{24} \times \text{Ave. No. Cars in Train.}$$

$$\text{Unit Cost of Car Delay} = \text{Ave. Car Days Delay} \times \text{Car Day Value.}$$

39. Costs of Delays on Cars with Hot Boxes

The unit costs of car delays to the cars actually having the hot boxes, Table 21, are based on the average delays to cars found in Appendix B, Tables 12 and 13, and on the car day value as shown above.

Table 20

Unit Costs of Car Delays in Train

Class of Delay	Ave. Train Delay Hours	Average Car Delay, Days		Unit Cost of Car Delay	
		1948	*1951*	*1948*	*1951*
I. *Railroad A*					
Set-off and Pickup	0.700	1.660	1.631	$8.975	$14.719
II. *Railroad B*					
Set-off and Pickup	0.850	2.136	2.123	11.554	19.170
Set-off, Pickup, and Rebrass	1.267	3.183	3.164	17.222	28.574
Set-off, Pickup, and Other Work	1.100	2.764	2.747	14.952	24.808
Rebrass	0.583	1.465	1.456	7.925	13.148
Other Work	0.417	1.048	1.041	$ 5.668	$ 9.404

Table 21

Unit Costs of Car Delays on Cars With Hot Boxes

Type of Hot Box	Ave. Car Delay, Days	Unit Cost of Car Delay	
		1948	*1951*
I. *Railroad A*			
Set-offs:			
Road Rebrass	1.70	$ 9.197	$15.351
To Repair Track	3.34	18.069	30.160
Other Than Set-offs:			
Cut Journal	2.30	12.433	20.769
Rebrass or R and R	2.05	11.091	18.511
II. *Railroad B*			
Set-offs:			
To Destination	2.20	11.902	19.866
To Repair Track	3.93	21.261	35.488
Other Than Set-offs:			
Cut Journals	2.26	12.227	20.408
Rebrass	1.93	10.441	17.428
R and R	1.62	$ 8.764	$14.629

40. Costs of Labor

(a) Road Repairs by Repair Track Forces — One item in the cost of hot boxes is the cost of repairs and inspections made to cars developing the hot boxes at the station at which the cars are set off. Where such repairs are made by train crews, as was frequent on Railroad B, the cost has been evaluated by use of the Train Hour Value and appropriate material charges. To determine the cost of such repairs when made by repair track forces, special studies were conducted on both railroads, the results of which are shown in Table 22. On both railroads the repairs made by repair track forces usually involved a road trip in a small truck sent out from permanently located repair tracks.

Railroad A — Usually only one man was sent out to make road repairs, which ordinarily were limited to rebrassing of the car. A study of time slips, repair records, and truck mileage was made for work done by a man on Division 1. The work done by this man during the months of July, September, October, and December 1948 is included in the results summarized at the end of this section.

Railroad B — Usually two or more men were sent out to make road repairs. Both rebrassing and rewheeling of cars was done, the type of repairs depending on the distance to the nearest repair track and the condition of the overheated journal. A study of time slips, repair records, and truck mileage was made for work done during the entire year by men sent out from two repair points, one on Division 1 and the other on Division 5.

Table 22

Samples of Road Repairs to Hot Boxes, 1948

Location Repairs Made	No. of Cars Repaired	Total Number of Labor, Hours		Truck Miles	Ave. per Car Repaired Labor, Hours		Truck Miles
		Worked	Paid for		Worked	Paid for	
I. *Railroad A*							
Rebrasses							
Div. 1	158	402.00	432.67	6729	2.54	2.74	42.6
II. *Railroad B*							
Rebrasses							
Div. 1	35	207.00	242.50	1986	5.91	6.92	56.7
Div. 5	28	215.00	230.50	2253	7.67	8.23	80.5
Total	63	422.00	473.00	4239	6.70	7.51	67.3
Cut Journals							
Div. 1	83	1469.00	1770.75	6464	17.70	21.32	77.9
Div. 5	13	244.00	288.00	1621	18.78	22.18	124.6
Total	96	1713.00	2058.75	8085	17.85	21.45	84.2

Table 23

Unit Costs of Road Repairs to Hot Boxes

Railroad	Type of Repairs	Labor, Hours Paid for	Truck Miles	Unit Costs: Labor		Unit Costs: Truck Miles	Unit Costs: Total	
				1948	*1951*		*1948*	*1951*
A	Rebrasses	2.74	42.6	$ 6.16	$ 8.63	$3.62	$ 9.78	$12.25
B	Rebrasses	7.51	67.3	16.90	23.66	5.72	22.62	29.38
	Cut Journal	1948—22.57 1951—22.77	84.2	$50.78	$71.73	$7.16	$57.94	$78.89

In figuring unit costs of these road repairs the following basic costs were used:

Truck expense 8.5¢/mile
Labor rate (AAR) 1948: $2.25/Hr.
1951: 3.15/Hr.

The time shown in Table 22 for cut journals does not include wheel shop and wheel handling labor. The time allowed by the AAR for these operations was 1.12 hours in 1948 and 1.32 hours in 1951. This allowance has been included in the unit costs of road repairs developed in Table 23.

(b) Labor and Overhead Costs of Work Done to Hot Boxes on Repair Tracks — The basis of labor charges for work done on the repair track may be found in the AAR Code of Rules. The charges made under these rules include no element of profit, but are intended to cover all items of direct and indirect expense associated with the work. The hours charged to each operation are the direct result of time studies, the indirect expense

being covered by application of a labor rate which has been adjusted to include this expense. The items of indirect expense included in this labor rate may be found in Rule 107 of the Code. The importance of these items is indicated by the fact that actual direct labor costs account for only 60 percent (approximately) of the labor rate which is used. The cost of switching cars to repair tracks is included in the hourly rate for repair track labor. For this reason the cost of switching cars to the repair track is not included in the unit cost of repairs to hot boxes.

The 1951 Code increased the allowance for change of wheels by two-tenths of an hour because of the time needed to magnaflux axles. Regarding the items used in working out unit costs for cut journals, the hours allowed for wheel change involving a unit-type truck side have been used because a study of 576 cars with hot boxes on Railroad A showed that 485, or 84.2 percent, were equipped with unit-type truck sides. Similarly, the jacking charge for a loaded car has been used because approximately 93 percent of the hot boxes are on loaded cars. The charges used for cut journals include no allowances for R and R or R of brake beam or bottom rod safety supports in connection with the wheel change.

The prices for labor were obtained from July revisions of the Code of Rules for both 1948 and 1951. Sample calculations for labor costs are shown for 1948 with appropriate references to Rule 107 of the AAR Code. Since the values listed in Rule 107 are subject to change, it would be necessary in further studies to use the prevailing values.

Sample Calculations Illustrating Unit Labor Costs, 1948

Items refer to Rule 107 Reference Numbers

A. Cut Journal

1st Pair of Wheels on Car

(Item 165 − Note Under Item 168 + Item 83) × Item 92

(5.0 Hrs. − 1.2 Hrs. + 1 Hr.) × \$2.25

4.8 Hours × \$2.25 = \$10.80

2nd Pair of Wheels on Same Car

Assuming 2nd Pair of Wheels was at same end of car as First Cut Journal on 50% of the Wheels

$$\frac{(4.8 \text{ Hrs.} + \text{Item } 167 - \text{Note under Item } 168) \times \text{Item } 92}{2}$$

$$\frac{(4.8 \text{ Hrs.} + 2.4 \text{ Hrs.} - 1.2 \text{ Hrs.}) \times \$2.25}{2}$$

3.0 Hours × \$2.25 = \$6.75

B. Rebrass and R and R

Item 89 × Item 92

0.5 Hrs. × \$2.25 = \$1.125

These calculations, and similar ones for 1951, served as a basis for the preparation of Table 24.

Table 24

Unit Labor and Overhead Costs of Repairs to Hot Boxes

Type of Hot Box	Hours of Labor		Unit Cost	
	1948	*1951*	*1948*	*1951*
Cut Journal, First Pair of Wheels in Car	4.8	5.0	$10.80	$15.75
Cut Journal, Second Pair of Wheels in Car	3.0	3.2	6.75	10.08
Rebrass or R and R	0.5	0.5	$ 1.125	$ 1.575

Table 25

Unit Costs of Items in Material Costs

Item	Railroad A		Railroad B	
	1948	*1951*	*1948*	*1951*
Journal Bearing (AAR Code Rule 101, Item 162D)	$2.6800	$2.8700	$2.6800	$2.8700
Dust Guard (AAR Code Rule 101, Item 163)	0.1700	0.1900	0.1700	0.1900
Dust Guard Plug	0.0200	0.0200	0.0200	0.0650
Journal Box Packing, per lb.	0.0350	0.0784	0.0382	0.0503
Journal Box Packing, per Journal Box (9 lb.)	0.3150	0.7060	0.3440	0.4530
Flame Depressant, per lb.	0.1920	0.1914	0.1600	0.2080
Flame Depressant, per Journal Box (1.5 lb.)	$0.2880	$0.2870		
(0.925 lb.)			$0.1480	$0.1920

Table 26

Unit Costs of All Material Used in Various Types of Hot Boxes

Type of Hot Box	Packing: Boxes Used	Packing: Cost	Bearings: No. Used	Bearings: Cost	Dust Guards and Plugs: No. Used	Dust Guards and Plugs: Cost	Total
I. *Railroad A, 1948*							
Cut Journal							
1st axle	4	$1.260	2	$5.360	2	$0.380	$7.000
2nd axle	2	0.630	2	5.360	2	0.380	6.370
Rebrass	1	0.315	1	2.680			2.995
R and R	1	0.315					0.315
For set-offs to repair track where Flame Depressant is used add $0.288 to $2.995 (Rebrass) to get							3.283
II. *Railroad A, 1951*							
Cut Journal							
1st axle	4	2.824	2	5.740	2	0.420	8.984
2nd axle	2	1.412	2	5.740	2	0.420	7.572
Rebrass	1	0.706	1	2.870			3.576
R and R	1	0.706					0.706
For set-offs to repair track where Flame Depressant is used add $0.287 to $3.576 (Rebrass) to get							3.863
III. *Railroad B, 1948*							
Cut Journal							
1st axle	4	1.376	2	5.360	2	0.380	7.116
2nd axle	2	0.688	2	5.360	2	0.380	6.428
Rebrass	1	0.344	1	2.680			3.024
R and R	1	0.344					0.344
Other Work	½	0.172					0.172
For set-offs to repair track or repairs preliminary to set-off where Flame Depressant is used add $0.148 to $3.024 (Rebrass) to get							3.172
or add $0.148 to $0.172 (Other Work) to get							0.320
IV. *Railroad B, 1951*							
Cut Journal							
1st axle	4	1.812	2	5.740	2	0.510	8.062
2nd axle	2	0.906	2	5.740	2	$0.510	7.156
Rebrass	1	0.453	1	$2.870			3.323
R and R	1	0.453					0.453
Other Work	½	$0.226					0.226
For set-offs to repair track and repairs preliminary to set-off where Flame Depressant is used add $0.192 to $3.323 (Rebrass) to get							3.515
or add $0.192 to $0.226 (Other Work) to get							$0.418

41. Material Costs on Repairs to Hot Boxes

The materials used have been charged at the prices and credits given in Rule 101 of the AAR Code of Rules. The charges include storeroom expenses, interest on stock investment, transportation charges, and (where it is involved) local manufacturing labor. No element of profit has been included.

The AAR Code does not include costs of packing, flame depressant, or dust guard plugs.

The costs of packing and flame depressant were obtained from the Store Department of each railroad. The costs of dust guard plugs were obtained from Railroad B for 1951, but for 1948 for both railroads and for Railroad A in 1951 it was assumed.

Where AAR prices were used, the unit prices of materials were obtained from the July revisions of the Code for both 1948 and 1951. To simplify the unit cost calculations it was assumed that 5½-x-10-in. journal bearings were used in the repairs, an assumption that should yield a close approximation of actual average and total costs. It was also assumed that repairs used 9 lb of packing per journal box repacked.

The unit costs of material items are shown in Table 25 and the resulting unit material costs for various repairs are shown in Table 26.

APPENDIX G: STUDIES OF PERIODIC ATTENTION TO JOURNAL BEARING ASSEMBLIES

The periodical repacking of journal boxes as required under Rule 66 of the AAR Code was investigated by taking samples of billing and repair cards for cars shown repacked according to its provisions.

The cars included in the samples were repacked during 1948, when Rule 66 provided for a basic time period of 15 months between complete inspections of the bearing assembly.

42. Results of Special Studies

Table 27 contains a summary of all information obtained in the special studies; and Table 28 contains complete data regarding prior repacking dates.

(a) Railroad A — The investigation on Railroad A was made by obtaining data concerning the repairs made to 2934 cars at two points on Division I.

The two points were chosen so that a combination of the data obtained from the points would be representative of the work done under this rule on Railroad A with regard to the distribution of the date of previous periodical repacking. Since local conditions greatly affect bearing renewal, the values obtained for the average number of journal bearings renewed per car at the time of repacking, condemned by provisions of Rule 66, are probably not representative of the values which prevailed for the entire system.

The provisions of Rule 66 tend to make work done to foreign freight cars follow a fairly uniform pattern. The repairs made to system cars, while they are of the same physical sort, will not necessarily follow the pattern of repairs to foreign cars with respect to the prescribed time intervals for repacking.

On Railroad A a large number of system cars were repacked while on the repair track for other work. Cars were repacked if deemed necessary, regardless of the last repacking date. The procedure used on empty system cars not repacked within 15 months was the same as that used on similar foreign cars. In general the manner of handling the repacking of system cars on Railroad A shortens the average period between repacks. For system cars with the old date given on the repair card the average age of the old repack date was 12.5 months; for foreign cars, it was 17.0 months.

Table 27

Summary of Data Obtained in Studies of Periodical Repacking, 1948

	Railroad A		Railroad B	
	System	Foreign	System	Foreign
1. Age of Prior Repacking Date, Mo. (Percent Distribution for Cars with Old Dates Stated)				
Over Under				
0 — 4	1.20%	0.19%	1.58%	0.22%
4 — 9	18.45	0.78	4.27	3.98
9 — 14	43.95	15.50	34.76	31.22
14 — 15	8.03	5.81	8.69	12.43
15 — 16	9.57	17.11	15.96	17.42
16 — 17	7.86	19.77	10.59	13.36
17 — 18	4.79	11.50	7.26	6.93
18 — 19	2.74	7.63	5.05	4.48
19 — 20	0.85	5.88	3.00	3.25
20 — 21	1.03	3.55	1.90	2.38
21 — 24	0.85	6.78	4.27	2.96
24 — 27	0.17	2.98	1.26	0.80
27 — 30	0.34	1.49	0.47	0.14
30 — 36	0.17	0.71	0.47	0.36
36 — up	....	0.32	0.47	0.07
Total	100.00%	100.00%	100.00%	100.00%
2. Average Age of Prior Repacking Date, Mo. (for Cars with Old Dates Stated)	12.5	17.0	15.0	14.8
3. Number of Cars in Sample				
a. Old Date Stated	585	1,548	633	1,384
b. Old Date Not Stated	779	22	254	3
c. Total	1,364	1,570	887	1,387
4. Cars Repacked in Conjunction with Wheel Change				
a. Old Date Under 15 Mo.	159	283	141	543
b. Old Date Over 15 Mo.	27	130	52	163
c. Old Date Not Stated	30	2	81	1
d. Total	216	415	274	707
5. Total Wheels Changed, Pairs	253	458	383	981
6. Bearings Applied				
a. Account of Wheel Change	506	916	737	1,906
b. Account of Rule 66	2,194	3,549	480	1,267
c. Total	2,700	4,465	1,217	3,173
7. Bearings Applied Account of Rule 66, per Car	1.61	2.26	0.54	0.91
8. Percent of Cars Repacked in Conjunction with Wheel Change of Cars in Age Group				
a. Old Date Under 15 Mo.	38.0	82.0	45.2	82.0
b. Old Date Over 15 Mo.	16.3	10.8	16.2	22.6
c. Old Date Not Stated	3.9	9.1	31.9	33.3
d. Total	15.8	26.4	30.9	51.0

Data obtained from the two chosen points indicate that 82.0 percent of the foreign cars repacked before the expiration of the 15 months are "bad ordered" for wheel defects. A large number of the remaining 18.0 percent of this group were repacked because they were on the repair track after the expiration of 14 months. The rest of the group were repacked in connection with renewal of truck sides or because of derailment.

(b) Railroad B — The investigation was made by obtaining data concerning the repairs made to 2274 cars at eleven points on all nine divisions of Railroad B.

The data obtained should be representative of the work done under this rule on Railroad B. The average number of journal bearings renewed per car at the time of repacking, condemned by provisions of Rule 66, was approximately 0.77 for the cars included in this study. An estimate of the bearings applied exclusive of wheel changes on the entire railroad, based in part on this figure, differed by only 0.91 percent from the total

Table 28

Age Distribution of Prior Repacking Dates on Cars Included in Study of Periodical Repacking, 1948

Age of Prior Repacking Date, Mo.		Railroad A		Railroad B	
Over	Under	System	Foreign	System	Foreign
1	2	1		3	
2	3	3	1	4	1
3	4	3	2	3	2
4	5	4	3	5	4
5	6	11	3	4	16
6	7	21	3	8	16
7	8	26	1	3	12
8	9	46	2	7	7
9	10	51	34	22	59
10	11	54	45	36	91
11	12	58	51	38	104
12	13	44	65	64	89
13	14	50	45	60	89
14	15	47	90	55	172
15	16	56	265	101	241
16	17	46	306	67	185
17	18	28	178	46	96
18	19	16	118	32	62
19	20	5	91	19	45
20	21	6	55	12	33
21	22	3	35	11	16
22	23	1	42	12	14
23	24	1	28	4	11
24	25	1	15	4	5
25	26		11	1	5
26	27		20	3	1
27	28	1	8	2	1
28	29	1	9		1
29	30		6	1	
30	31		3		1
31	32	1	4	1	2
32	33		1	1	
33	34		2	1	2
35 and over			6	3	1
Total Cars with Old Dates Stated		585	1,548	633	1,384
Total Cars Old Dates Not Stated		779	22	254	3
Grand Total Cars in Sample		1,364	1,570	887	1,387

shown by railroad repair track performance reports. The figure for average number of bearings applied per car because of Rule 66 is therefore considered representative of conditions on the entire railroad. The sampling of points on all nine divisions of the railroad probably aided greatly in obtaining representative data.

On Railroad B a large number of system cars were repacked while on the repair track for other work when the prior repacking date was approximately a year or more old. The procedure used on empty system cars also allowed for the bad ordering of cars for repacking when it was deemed necessary, usually when the prior repacking date was over a year old. In general the manner of handling the repacking of system cars on Railroad B shortens the average period between repacks. However, for system cars in the sample with the old date given on the repair card the average age of the old repack date was 15.0 months; for foreign cars, 14.8 months. The reason for this apparent discrepancy lies in the differences in the relative proportions of cars repacked in conjunction with wheel changes.

The reasons for repacking foreign cars before the expiration of 15 months were practically identical with those found on Railroad A.

43. Percent of Cars Bad Ordered for Repacking

(a) Railroad A

1. Foreign Cars (Based on Entire Sample Data)

$$= \frac{100\ (\text{Foreign Cars with Old Date Illegible or Over 15 Mo.} - \text{Cars with Whl. Chg. Over 15 Mo.})}{\text{Total Foreign Cars}}$$

$$= \frac{100\ (1225 - 130)}{1570} = 69.7\%$$

2. System Cars

The previous repacking date was missing from over 95 percent of the system repair cards at one of the chosen points and this distorts the information regarding bad ordering procedure, since one-third of the repacking of system cars at the other point was in conjunction with wheel changes. What data was obtained served as basis for estimating that 50 percent of the total system cars were actually bad ordered for that purpose.

3. Total Cars

For the over-all total of system and foreign cars, approximately 60 percent of the cars repacked were bad ordered for that purpose.

(b) Railroad B—The data for determining the percent of cars bad ordered for repacking was obtained in conjunction with the study previously discussed, but only at four selected points of the eleven repair points, where samples were taken. At these points the most reliable information could be obtained. The billing and repair card showed the reason for which the car was bad ordered. For all data obtained, 48.8 percent of the cars repacked were bad ordered for that purpose.

Cars Bad Ordered for Periodical Repacking, Percent of Cars in Sample

	No. of Repair Points	*System Cars*			*Foreign Cars*			*Total Cars*		
		No. Repacked	Bad Ordered No.	Bad Ordered %	No. Repacked	Bad Ordered No.	Bad Ordered %	No. Repacked	Bad Ordered No.	Bad Ordered %
Div. 2	1	40	31	77.5	25	10	40.0	65	41	63.0
Div. 6	1	197	103	52.2	224	58	25.9	421	161	38.2
Div. 7	1	84	63	75.0	189	95	50.3	273	158	57.8
Div. 8	1	16	15	93.7	75	40	53.3	91	55	60.5
Total		337	212	63.0	513	203	39.5	850	415	48.8

APPENDIX H: METHODS AND INFORMATION USED TO DETERMINE COSTS OF SOLID JOURNAL BEARING OPERATION

44. Development of Determined Costs

The material contained in this section was used in the preparation of the simplified costs per 1000 car miles presented in Chapter IV. Wherever car miles were used for an index of comparison, the car miles used consisted of the sum of the loaded freight, empty freight, and caboose car miles in freight trains.

Total hot box costs were determined by simply multiplying the number of cases by the appropriate unit costs. The methods used to compute the number of cases of each type of hot box are illustrated in Appendix A; the unit costs are developed in Appendix F. Tables 29 and 30 constitute a summary for the year 1948 of the number of cases and the unit costs for Railroads A and B respectively. Similar tables for 1951 could be prepared from data contained in Tables 4 (Road A) and 6 (Road B), and from the unit costs given in Appendix F.

Average unit costs of hot boxes might be of greater interest than the types of unit costs shown in Tables 29 and 30. Such average unit costs are as follows:

	1948		*1951*	
Average Unit Cost	*A*	*B*	*A*	*B*
(1) Hot box set-offs (all costs on set-offs divided by the number of set-offs)	\$74.210	\$127.512	\$99.414	\$160.820
(2) Other hot boxes (all costs on other hot boxes divided by the number of other hot boxes)	\$23.384	\$ 25.127	\$35.584	\$ 32.920

Since set-offs are the only number of cases generally known on most railroads, the relation of total hot box costs to the number of set-offs might also be valuable.

	1948		*1951*	
	A	*B*	*A*	*B*
Hot box costs per hot box set-off	\$114.653	\$300.534	\$153.212	\$386.385

The number of hot boxes assigned to each bar graph of Fig. 3 was as follows:

	1948	*1951*
Bars (1) — The number of set-offs		
Railroad A	8,322	12,420
Railroad B	3,505	5,569
Bars (2) — Those of bars (1) plus the road delays preliminary to set-offs		
Railroad A	8,322	12,420
Railroad B 3505 + 1739	5,244	
5569 + 2763		8,332

			1948	1951
Bars (3) — Those of bars (2) plus the road delays on cars which had hot boxes between terminals but were not set off				
	Railroad A		8,322	12,420
	Railroad B	5244 + 2291 + 9674	17,209	
		8332 + 3640 + 15,371		27,343
Bars (4) — Those not included in bars (3). Essentially, this includes all hot boxes discovered in yards.				
	Railroad A	14,393 + 183	14,576	
		18,777 + 273		19,050
	Railroad B	5664 + 289 + 5612 + 605 + 100	12,270	
		8911 + 454 + 8831 + 951 + 158		19,305
Bars (5) — Those of bars (2) plus those of bars (4)				
	Railroad A	8322 + 14,576	22,898	
		12,420 + 19,050		31,470
	Railroad B	5244 + 12,270	17,514	
		8332 + 19,305		27,637

The amounts of materials used in solid journal bearing service are shown in Table 31. Stores Department reports of materials issued were used as a basis for most of Table 31. The table does not include the oil and packing used, since these items are included under routine inspection and lubrication costs. The number of wedges used has been reduced to an equivalent number of pounds, since wedges are priced on a cost per pound basis. The table also shows the amounts of materials which have been charged to service failures.

The unit costs of and the amounts of materials which have not been otherwise assigned to service failures or routine inspection and lubrication are shown in Table 32. Where available, the difference between the price and credit given in Rule 101 of the AAR Code of Rules has been used for unit cost of the material involved. The July revisions of the Code of Rules for both 1948 and 1951 were used. Where applicable, Table 32 shows appropriate references to AAR Code Rule 101. The unit costs of special dust guards and flame depressant were obtained from the Stores Department of each railroad. The unit cost of dust guard plugs was obtained from Railroad B for the year 1951. For Railroad A in 1951 and for both railroads in 1948 this value was assumed. The unit cost of second-hand journal bearings used on Railroad B was assumed as equivalent to the cost of 0.2 hour of labor at the prevailing AAR rate.

Information regarding routine inspection and lubrication costs is shown in Table 33. The unit costs of oil and packing were obtained from the Stores Department for each railroad. The hourly rate for freight car oilers was derived from the AAR labor rate for passenger car lubrication and the ratio of the freight car repair labor rate to the passenger car repair labor rate. The AAR labor rate for freight car repairs was used for an hourly rate for car inspectors. The car delays were evaluated by use of the car day values developed in Appendix E.

The calculations shown for various items contained in Table 33 are largely self-explanatory. The assumption made in calculation 5e, where

Table 29

Number of Cases and Unit Costs Used to Compute Hot Box Costs: Railroad A — 1948

	Cut Journals		Rebrass	R and R	Road Rebrass
	1st Axle	2nd Axle, Same Car			
I. *Hot Boxes on Cars Set Off*					
A. Number of Cases	5722	183	628	761	1211
B. Unit Costs					
1. Delay Costs					
Train Delays	$22.467		$22.467	$22.467	$22.467
Car Delays in Train	8.975		8.975	8.975	8.975
Car Delays on Car Set-off	18.069		18.069	18.069	9.197
2. Labor Costs					
Road Repairs	9.780		9.780	9.780	9.780
Repair Track	10.800	$ 6.750	1.125	1.125	
3. Material Costs					
Road Repairs	3.283		3.283	3.283	2.995
Repair Track	7.000	6.370	2.995	0.315	
4. Total Unit Costs	$80.374	$13.120	$66.694	$64.014	$53.414
II. *Other Hot Boxes*					
A. Number of Cases	8099	259	4733	1302	
B. Unit Costs at Repair Track					
1. Car Delays	$12.433		$11.091	$11.091	
2. Labor	10.800	6.750	1.125	1.125	
3. Material	7.000	6.370	2.995	0.315	
4. Total Unit Costs	$30.233	$12.120	$15.211	$12.531	

Table 30

Number of Cases and Unit Costs Used to Compute Hot Box Costs: Railroad B — 1948

I. *Hot Boxes on Cars Set Off*

A. Delays Prior to Set-off

	Rebrass	Other Work
1. Number of Cases	743	996
2. Unit Costs		
a. Train Delays	$28.473	$20.366
b. Car Delays in Train	7.925	5.668
c. Material	3.024	0.320
d. Total Unit Costs	$39.422	$26.354

B. Set-offs—Road Repairs by Train Crews

	To Repair Track					To Destination
	Cut Journals		Rebrass		R and R	
	1st Set-off	Additional Set-offs (Same Cars)	Rebrassed on Road	Other Work on Road		Road Rebrass
1. Number of Cases	1635	93	338	408	20	550
2. Unit Costs						
a. Train Delays	$61.879	$61.879	$61.879	$53.723	$53.723	$61.879
b. Car Delays in Train	17.222	17.222	17.222	14.952	14.952	17.222
c. Car Delays on Car Set-off	21.261	11.902	21.261	21.261	21.261	11.902
d. Labor, Repair Track	10.800		1.125	1.125	1.125	
e. Material, Road Repairs	3.172	3.172	3.172	0.320	0.320	3.024
f. Material, Repair Track	7.116		3.024	3.024	0.344	
g. Total Unit Costs	$121.450	$94.175	$107.683	$94.405	$91.725	$94.027

C. Set-offs—Road Repairs by Track Forces

	To Repair Tracks—Cut Journals		To Destination	
	1st Set-off	Additional Set-offs (Same Cars)	Cut Journals	Rebrass
1. Number of Cases	78	26	263	94
2. Unit Costs				
a. Train delays	$41.513	$41.513	$41.513	$41.513
b. Car Delays in Train	11.554	11.554	11.554	11.554
c. Car Delays on Car Set-off	21.261	11.902	11.902	11.902
d. Labor, Road Repairs	22.620	22.620	57.940	22.620
e. Labor, Repair Track	10.800			
f. Material, Road Repairs	3.172	3.172	7.116	3.024
g. Material, Repair Track	7.116			
h. Total Unit Costs	$118.036	$90.761	$130.025	$90.613

II. *Other Hot Boxes*

	Cut Journals		Rebrass	R and R	Train Delays	
	1st Axle	2nd Axle*			Rebrass	Other Work
A. Number of Cases	5664	289	5612	605	2291	9674
B. Unit Costs						
1. Train Delays					$28.473	$20.366
2. Car Delays in Train					7.925	5.668
3. Car Delays at Repair Track	$12.227		$10.441	$ 8.764		
4. Labor, Repair Track	10.800	$ 6.750	1.125	1.125		
5. Material	7.116	6.428	3.024	0.344	3.024	0.172
6. Total Unit Costs	$30.143	$13.178	$14.590	$10.233	$39.422	$26.206

* There were also 100 additional cases where second axles were applied to cars set off at the same unit cost.

Table 31

Amounts of Materials Used in Solid Journal Bearing Service

Description	Size	Number Used 1948 A	1948 B	1951 A	1951 B
I. *Total Materials Used*					
Journal Bearings, New or Relined	7″	4			
	8″	1,993	2,569	2,088	1,186
	9″	62,216	52,705	72,124	39,773
	10″	96,621	58,303	146,383	66,550
	11″	9,764	5,260	23,975	8,711
	12″	12		85	
Total		170,610	118,837	244,655	116,220
Journal Bearings, Second Hand	All		17,738		31,648
Total		170,610	136,575	244,655	147,868
Box Lids	8″, 9″, 10″	33,926	26,343	32,159	26,633
	11″	1,220	675	2,913	1,228
Total		35,146	27,018	35,072	27,861
Dust Guards, Regular	All	85,818	88,333	149,163	69,273
Dust Guards, Special	All				37,938
Total		85,818	88,333	149,163	107,211
Dust Guard Plugs	All	85,818	88,333	149,163	96,306
Wedges (Pounds)	All	53,794	209,451	112,746	150,267
Flame Depressant (Pounds)		10,666	3,332	52,765	18,332
Axles*					
	7″		7		
	8″		736		176
	9″		6,233		3,490
	10″	4,766	1,473	5,338	2,600
	11″		81		82
	12″				8
Total		4,766	8,530	5,338	6,356
II. *Materials Assigned to Service Failures*					
Journal Bearings, New or Relined	10″	42,209	28,264	58,966	44,559
Dust Guards, Regular	All	28,526	16,058	39,434	25,266
Dust Guard Plugs	All	28,526	16,058	39,434	25,266
Flame Depressant (Pounds)		10,666	3,332	15,918	5,247

* Axles on Railroad A computed;
Weight of Scrap Axle, 10″ size, 775 lb

Scrap Axle Tonnage	
1948	*1951*
1846.8	2068.4

delays per 1000 car miles for 1951 are assumed to be the same as for 1948, may be questioned because the amount of labor assigned to lubrication changed. However, most of the changes in labor assignments were made on repair tracks and in terminals which were not included as oiling stations. Therefore the assumption of calculation 5e is probably a reasonable one.

The number of terminal lubrications used to compute delays in calculation 5 is not excessive. This may be illustrated by comparing the number of lubrications to the number of individual car movements in the corresponding period.

	Railroad A	*Railroad B*
(1) Cars Lubricated in Terminal Oiling Stations	2,767,294	3,122,926
(2) Total Number of Car Movements	3,332,687	2,045,571
(3) Number of Times Car Lubricated per Movement (Item 1/Item 2)	0.830	1.527

Item 2 above was developed in the following manner:

$$\text{Non-Rev. Carloads} = \frac{\text{Tons of Non-Rev. Freight}}{\text{Tons of Rev. Freight}} \times \text{Revenue Carloads}$$

$$\text{Total Carloads} = \text{Non-Rev. Carloads} + \text{Rev. Carloads}$$

$$\text{Empty Car Movements} = \frac{\text{Empty Car Miles}}{\text{Loaded Car Miles}} \times \text{Total Carloads}$$

$$\text{Total Car Movements} = \text{Empty Car Movements} + \text{Total Carloads}$$

The number of wheels changed for causes other than cut journals and the unit costs of turning axle journals and collars on these wheels are shown in Table 34. The unit cost of turning axle journals and collars is equivalent to the cost of 32.5 minutes of labor at the prevailing AAR rate. The total cost of this maintenance was found by multiplying the values in Column (3) by the corresponding values in Column (4).

Calculations for Items Contained in Table 33

(1) Packing Assigned to Routine Inspection and Lubrication

	Total Packing Used, Lb.	Packing Assigned to Service Failures, Lb.	Packing Assigned to Routine Inspection and Lubrication, Lb.
Railroad A — 1948	6,485,000	647,226	5,837,774
1951	6,365,000	900,099	5,464,901
Railroad B — 1948	4,069,058	447,462	3,621,596
1951	4,663,242	705,636	3,957,606

(2) Labor Rate for Freight Car Oilers

$$\text{Labor Rate, Frt. Car Oilers} = \text{Pass. Lub. Rate} \times \frac{\text{Frt. Repair Labor Rate}}{\text{Pass. Repair Labor Rate}}$$

	AAR Code Reference Rule	Item	*1948*	*1951*
Passenger Lubrication Labor, per hour	PC 21	19	\$1.80	\$2.25
Passenger Repair Labor, per hour	PC 21	20	2.50	3.45
Freight Repair Labor, per hour	107	92	2.25	3.15

$$\$1.80 \times \frac{\$2.25}{\$2.50} = \$1.6200$$

$$\$2.55 \times \frac{\$3.15}{\$3.45} = \$2.3282$$

(3) Inspector Man Hours

$$\text{Inspector Man Hours} = \frac{\text{Journal Inspection Time per Car}}{\text{Journal Oiling Time per Car}} \times \text{Oiler Man Hours}$$

Sample: Railroad A, 1948

$$= \frac{1.50 \text{ Minutes}}{4.00 \text{ Minutes}} \times 959{,}080$$

$$= 359{,}655$$

(4) Car Days Lost, Rule 66

For explanation of percent bad ordered for repacking of total cars repacked, see Appendix G

For explanation of days delay per car bad ordered, see Appendix B

	Total Cars Repacked	Percent Bad Ordered for Repacking	Days Delay per Car Bad Ordered	Total Car Days Delay
Railroad A 1948	76,232	60.0	2.05	93,765
1951	68,702	60.0	2.05	84,503
Railroad B 1948	42,810	48.8	1.83	38,231
1951	46,868	48.8	1.83	41,855

(Sample: $76{,}232 \times 0.600 \times 2.05 = 93{,}765$)

Table 32

Materials Used in Solid Journal Bearing Service Not Otherwise Assigned to Service Failures or Routine Inspection and Lubrication

Description	AAR Rule No. 101 Item	Size	Unit Cost 1948	Unit Cost 1951	Number Used 1948 A	Number Used 1948 B	Number Used 1951 A	Number Used 1951 B
Journal Bearings								
New or Relined	162-A	7″	$1.11	$1.20	4	0	0	0
	162-B	8″	1.67	1.86	1,993	2,569	2,088	1,186
	162-C	9″	2.31	2.51	62,216	52,705	72,124	39,773
	162-D	10″	2.68	2.87	54,412	30,039	87,417	21,991
	162-E	11″	3.78	3.97	9,764	5,260	23,975	8,711
	162-F	12″	4.69	4.88	12	0	85	0
Total					128,401	90,573	185,689	71,661
Second Hand		All	0.45	0.63		17,738		31,648
Grand Total					128,401	108,311	185,689	103,309
Box Lids								
	104-B	8-10″	1.95	2.07	33,926	26,343	32,159	26,633
	104-B	11″	2.31	2.28	1,220	675	2,913	1,228
Total					35,146	27,018	35,072	27,861
Dust Guards								
Standard	163	All	0.17	0.19	57,292	72,275	109,729	44,007
Special		All		0.2529				37,938
Total					57,292	72,275	109,729	81,945
Dust Guard Plugs								
Railroad A		All	0.02	0.02	57,292		109,729	
Railroad B		All	0.02	0.065		72,275		71,040
Wedges, Lb.	103	All	0.100	0.100	53,794	209,451	112,746	150,267
Axles								
40,000 Lb.	195	7″	15.25	23.15		7		
60,000 Lb.	196	8″	19.20	28.50		736		176
80,000 Lb.	197	9″	25.80	37.65		6,233		3,490
100,000 Lb.	198	10″	31.15	45.10	4,766	1,473	5,338	2,600
140,000 Lb.	199	11″	37.75	54.55		81		82
200,000 Lb.	200	12″	62.60	77.85				8
Total					4,766	8,530	5,338	6,356
Flame Depressant, Lb.								
Railroad A		None	0.1920	0.1914			36,847	
Railroad B		None	0.1600	0.2080				13,085

Table 33

Items Assigned to Routine Inspection and Lubrication Costs

Item	Amount Used	Unit Cost
I. *Railroad A, 1948*		
Oil, gallons	241,432	$0.2205
Packing, lb.	5,837,774	0.0350
Labor, man hours (Oilers)	959,080	1.6200
Labor, man hours (Inspectors)	359,655	2.2500
Car days lost (Rule 66)	93,765	5.4100
Car days lost (Train yard)	97,162	5.4100
II. *Railroad A, 1951*		
Oil, gallons	131,566	0.2560
Packing, lb.	5,464,901	0.0784
Labor, man hours (Oilers)	740,720	2.3282
Labor, man hours (Inspectors)	277,770	3.1500
Car days lost (Rule 66)	84,503	9.0300
Car days lost (Train yard)	101,260	9.0300
III. *Railroad B, 1948*		
Oil, gallons	150,171	0.2660
Packing, lb.	3,621,596	0.0382
Labor, man hours (Oilers)	619,648	1.6200
Labor, man hours (Inspectors)	232,368	2.2500
Car days lost (Rule 66)	38,231	5.4100
Car days lost (Train yard)	116,243	5.4100
IV. *Railroad B, 1951*		
Oil, gallons	115,201	0.3960
Packing, lb.	3,957,606	0.0503
Labor, man hours (Oilers)	626,168	2.3282
Labor, man hours (Inspectors)	234,813	3.1500
Car days lost (Rule 66)	41,855	9.0300
Car days lost (Train yard)	120,732	9.0300

Table 34

Data for Costs of Turning Axle Journals and Collars

		Pairs of Wheels Changed			Unit Cost of
		Total (1)	Cut Journals (2)	Other Causes (3) (1) − (2)	Turning Journals and Collars (4)
Railroad A	1948	46,638	14,263	32,375	$1.219
	1951	46,552	19,717	26,835	1.706
Railroad B	1948	46,997	8,029	38,968	1.219
	1951	45,752	12,633	33,119	1.706

(5) Car Days Lost, Train Yard Lubrication

A. Cars Departing from Terminal Oiling Stations During Year 1948 (including some estimated values)

Railroad A Oiling Station	Railroad A Number of Cars	Railroad B Oiling Station	Railroad B Number of Cars
1-2	590,293	1-3	200,000
2A	50,458	1A	100,000
2B	74,335	1B	400,000
3-4	263,581	2-3	80,000
4	243,242	2	100,000
5A	91,757	3A	330,000
5B	240,129	3B	109,002
5-7	585,948	2-4	300,000
6	254,282	4-5	292,339
8	82,106	5A	142,000
8-9	217,344	5B	49,179
9	73,819	5C	25,000
		5-6	196,790
		6	252,285
		6-7	229,716
		7-8	135,559
		8	80,000
		9	101,056
Total	2,767,294		3,122,926

B. Number of Trains $= \dfrac{\text{Number of Cars}}{\text{Ave. No. Cars per Train}}$

$$\text{Railroad A} = \frac{2{,}767{,}294}{56.88} = 48{,}651 \text{ Trains}$$

$$\text{Railroad B} = \frac{3{,}122{,}926}{60.30} = 51{,}790 \text{ Trains}$$

C. Oiling Time per Train $= \dfrac{\text{Oiling Time per Car}}{\text{Ave. No. Oilers on Duty}} \times$ Ave. No. Car per Train

$$\text{Railroad A} = \frac{4 \text{ Min.}}{3} \times 56.88 = 75.84 \text{ Min. or } 1.264 \text{ Hr.}$$

$$\text{Railroad B} = \frac{4 \text{ Min.}}{3} \times 60.30 = 80.40 \text{ Min. or } 1.340 \text{ Hr.}$$

D. Train Hours Delay = No. of Trains × Oiling Time per Train
Railroad A = 48,651 × 1.264 = 61,495 Train Hr.
Railroad B = 51,790 × 1.340 = 69,398.6 Train Hr.

E. Total Car Delays for Oiling

1948

$$\frac{\text{Train Hours Delay} \times \text{Ave. No. Cars per Train}}{24 \text{ Hr. per Day}}$$

$$\text{Railroad A} = \frac{61{,}495 \times 56.88}{24} = 145{,}743 \text{ Days}$$

$$\text{Railroad B} = \frac{69{,}398.6 \times 60.30}{24} = 174{,}364 \text{ Days}$$

1951

$$\frac{\text{Car Miles, 1951}}{\text{Car Miles, 1948}} \times \text{Car Days Delay, 1948}$$

Railroad A = 151,890 Days
Railroad B = 181,098 Days

F. Time Required for Train Inspection
From observations of conditions at various terminals, and from discussions with car inspectors and car foremen, it was estimated that without journal box lubrication, trains would be delayed only one-third of the time required with journal box lubrication.

G. Car Days Lost, Train Yard Lubrication
Car Days Lost = 2/3 × Total Car Delays for Oiling
Sample: Railroad A, 1948
Car Days Lost = 2/3 × 145,743
= 97,162

45. Number of Physical Units Represented in Determined Costs

In Table 35 the physical units of labor, truck mileage, train delay, car delay, and material which entered into the determined costs are presented, reduced to the number per million car miles. The units which entered into accident and fire costs were not determined and are not included.

The table was prepared for the main purpose of indicating what ranges of values may be expected in various items. Wherever wide differences are shown for various items, the reasons for the differences have usually been indicated in previous discussions (Sections 8, 9, 10, and 14).

Table 35

Number of Units per Million Car Miles

		1948 A	1948 B	1951 A	1951 B
Labor, Man Hr.	1. Service Failures	93.86	60.69	130.52	95.05
	2. Routine Inspection	358.44	296.94	265.63	288.91
	3. Turning Axle Journals	17.48	26.97	13.90	22.07
	4. Total	469.78	384.60	410.05	406.03
	5. Lubrication	955.85	791.85	708.35	770.42
	6. Grand Total	1425.63	1176.45	1118.40	1176.45
Truck Mileage		353.32	45.33	505.97	68.72
Train Delays, Hr.	1. Freight	5.98	13.56	8.60	20.79
	2. Passenger	0.03	0.04	0.05	0.07
Car Delays, Days	1. Service Failures	70.81	80.85	95.54	122.95
	2. Routine Inspection	96.83	148.55	96.83	148.55
	3. Rule 66	93.45	48.85	80.81	51.50
	4. Total	261.09	278.25	273.18	323.00
Material	1. Bearings, New				
	a. Service Failures	42.07	36.12	56.39	54.82
	b. Other	127.97	115.74	177.57	88.17
	c. Total	170.04	151.86	233.96	142.99
	2. Bearings, Used		22.67		38.94
	3. Bearings, Total	170.04	174.53	233.96	181.93
	4. Box Lids	35.03	34.53	33.54	34.28
	5. Wedges, lbs.	53.61	267.66	107.82	184.88
	6. Axles	4.75	10.90	5.10	7.82
	7. Dust Guards				
	a. Service Failures	28.43	20.52	37.71	31.09
	b. Other	57.10	92.36	104.93	100.82
	c. Total	85.53	112.88	142.64	131.91
	8. Dust Guard Plugs				
	a. Service Failures	28.43	20.52	37.71	31.09
	b. Other	57.10	92.36	104.93	87.40
	c. Total	85.53	112.88	142.64	118.49
	9. Flame Depressant, lbs.				
	a. Service Failures	10.63	4.26	15.22	6.46
	b. Other			35.24	16.10
	c. Total	10.63	4.26	50.46	22.56
	10. Oil, gallons	240.62	191.90	125.82	141.74
	11. Packing, lbs.				
	a. Service Failures	645.04	571.81	860.76	868.19
	b. Other	5818.00	4628.01	5226.06	4869.33
	c. Total	6463.12	5199.82	6086.82	5737.52

The one important exception to this generalization is the fluctuation which occurs in the amounts of some material items used. There is no conclusive evidence at hand which will explain these fluctuations.

The total car delays shown in Table 35 may be interpreted differently expressing the delays as the equivalent 24-hour day annual services of a number of cars. This number of cars may then be reduced to a percentage of the freight cars on lines of the two railroads during the given periods. The results of such a procedure yielded results as follows:

	1948	*1951*
Total car delays shown in Table 35, equivalent number of cars		
Railroad A	716	783
Railroad B	595	719
Equivalent number of cars, percent of cars on line		
Railroad A	1.37%	1.44%
Railroad B	1.37%	1.69%

Table 35 also provides for the possibility of arriving quickly at a separate estimate of determined costs of solid journal bearing operation regardless of the values used for unit costs.

APPENDIX I: REFERENCES

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